Trade, growth, regions, and the environment

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Trade, Growth, Regions, and the Environment: Input-Output Analyses of the Chinese Economy

Proefschrift

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To my wife and son

Preface

Here comes the most exciting moment. This book contains my work for the "R*u*G part" of the "*double-Ph.D. degree program*", which was jointly set up by the University of Groningen and the Graduate University of the Chinese Academy of Sciences in Beijing. It's benefited from many individuals (an incomplete list is given below) in different ways, directly or indirectly.

First and foremost, my deep appreciation goes to my supervisors: Prof. Jan Oosterhaven and Prof. Erik Dietzenbacher for the "Groningen thesis", and Prof. Xikang Chen and Prof. Cuihong Yang for the "Beijing thesis". To acknowledge them, I will start with Jan. I still remember the first time when we met in 2007; I was so upset, standing in front of his office. That nervousness was gone immediately when Jan went directly to talk about our research interests. Afterwards, I joined a boat trip with the research group when he explained how the dam works to let the boat go through via adjusting the water level and everything. It turned out to be an amazing journey (my very first boat experience).

In fact, along with more and more contact, we become very good friends, talking about football, hanging out together in the bar when we were in Sydney, and so on. These aspects may seem to be loosely related to the research; conversely, they are vital factors to guarantee a smooth and fruitful study. "Be critical" is the first lesson I have learnt from Jan, which can be thought of as an enormous "cultural shock" that I encountered (because it is so different from the Chinese way of thinking). Obviously, it is very important for doing research. "Simplify, simplify" is the second important advice that I have received. The list of advices can be extended indefinitely. Further, I would like to thank Tineke for her generously letting Jan spend time to help revising the thesis after his official retirement, and of course for her hospitality and invitations to joining delicious dinners. Especially in the summer vacation of 2012, Jan was allowed to spend twice as much time as he was expected (three days a week), to work together and have discussions about the thesis.

Equally deep thankfulness goes to Erik, with whom I met two months prior to coming to Groningen, when he gave an advanced course on *Input-Output Economics* in Beijing. He is a nice, easy-going, and most importantly deep-thinking researcher. One of his frequently used words is “relax”; it comes when a certain idea is stuck or when proposing a new project. Whenever thinking of this word, a scene that springs to mind is him putting his legs on the desk and leaning back. Essentially, it has almost the same function as another phrase: “be patient”, which helps to do high quality research (recall also the “be critical”). “Be precise” and so forth, again, the list of advices can be extended indefinitely. It has really been a pleasure to work with him.

As mentioned above, I took part in the “*double-Ph.D. degree program*”, so my Chinese supervisors played an equally important role in the whole journey. I owe Prof. Chen and Prof. Yang deep gratitude for these years (since 2004) of continuous selfless help. Their influences are more imperceptible and gradual in nature on my character. Despite research, they have set a very good example of devoting time and effort to formulating policy-relevant reports so as to help the policy-makers towards a more scientific way of designing policy. As is widely known, Prof. Chen is famous for the development of the input-occupancy-output model (or input-output model extended with assets) and the precise prediction of China’s grain output (with less than 1.5% forecast error for over thirty years!). Moreover, they have always been willing to offer advices and suggestions on my work.

All in all, I have been very lucky. Again, to all of my supervisors: Prof. Jan Oosterhaven, Prof. Erik Dietzenbacher, Prof. Xikang Chen and Prof. Cuihong Yang, thanks a lot! Not so long ago, I was offered a tenure-track position (Assistant Professor) by the School of International Trade and Economics at the University of International Business and Economics, which means I can continue doing research and extend our collaboration in the long-run. Right now, I also want to express my deep thanks to the Vice-President (and former Dean of the School), Zhongxiu Zhao, and to the Vice-Dean, Ying Ge, for offering me a faculty position at the University.

I am obliged to my committee members, Prof. Pierre Mohnen from the University of Maastricht, Prof. Sandra Poncet from the University of Paris 1 (Panthéon Sorbonne), and Prof. Bert Steenge from the University of Groningen, who devoted their time and efforts to reading the thesis and sharing insightful comments with me. My appreciation goes to Yan Xu and Shu Yu for their willingness to be my paranymphs. Thanks also to those people who have provided comments and suggestions that have improved the quality of the thesis. To name a few, Dabo Guan,

Jiemin Guo, Bart Los, and Marcel Timmer, and participants at several seminars and conferences.

Also, I would like to express my sincere thanks to the members of the Research School SOM: Rina Koning, Arthur de Boer, Ellen Nienhuis, Astrid Beerta, Martin Land, Jakob de Haan and Tammo Bijmolt, and to Herma van der Vleuten at the GEM secretariat for their support and help in solving all kinds of administrative and legal issues. Rina helped to arrange copy-editing of thesis chapters and the translation of the Dutch summary, Arthur helped to tackle all the printing issues relating to this thesis, and Herma helped to arrange facilities during my stay at R*u*G this summer. Particular gratitude goes to the Ph.D. coordinator, Martin Land. It was he who helped me through a difficult time when I had a surgery on my leg in 2008, several times driving back and forth from Groningen to Stadskanaal for checking and re-checking. Obviously, without the help of all these people I would not have been able to finish the thesis in such a smooth way. Thank you very much. Thanks also go to the teachers at CAS who have contributed to establish and maintain the *program*, Prof. Hong Zhao and Dr. Qian Wang, among others.

I am also grateful to many people who have contributed indirectly to the present dissertation in the way of hanging out together (for dinner or at the bar), especially in the first year when I was a total stranger here. They are, among others, Maaike Bouwmeester, Justin Drupsteen, Rients Galema, Remco Germs, Jasper Hotho, Richard Jong-A-Pin, Tomek Katzur, Omid Madadi, Jochen Mierau, Boyana Petkova, Vaive Petrikaite, Janneke Pieters and Ryanne van Dalen. Thank you for having all the fun, and the nice memory-book that you have made. Especially, I am indebted to Justin who—with his friend—helped to transfer me from UMCG to Stadskanaal, and made sure everything was fine and ready for the surgery. Many thanks indeed!

I have also benefited from the input of many other individuals who have stimulated me during my study in one way or another, including Prof. Rencheng Tong and Prof. Jian Xu, and Quanrun Chen, Yuwan Duan, Abdul Azeez Erumban, Xuemei Jiang, Zhongbo Jing, Le Van Ha, Rujie Qu, Yusof Saari, Umed Temurshoev, Lan Wang, Taotao Wu, Weiguo Xia, Ling Yang, Huanjun Yu, Xuan Zhang, Yanping Zhao, Kunfu Zhu, Tao Zhu, and other colleagues both at CAS and at R*u*G. Thanks also go to colleagues at the UIBE and MOFCOM. These social contacts enrich my life experience and I am pretty sure that such good relationships will last long. Thank you all.

Last but not least, I would like to give my special thankfulness to my family, in particular, my wife Lina Liu. My obligations to her cannot be verbalized by any existing words. A more important regret is that during her pregnancy, I have only accompanied her couple of weeks. At this moment, deep thanks go to my mother-in-law who has taken good care of my wife and my baby son, both when I was in Groningen and back in China. It is true that I probably seem busy, and perhaps I am just not devoting enough time and effort to the family. Whatever the reasons, I hope I can (and intend to) do better as a husband and father in the future.

PEI, Jiansuo
October 28, 2012
Beijing, China

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Chapter 1

INTRODUCTION

[B]ut that trade which, without force or constraint, is naturally and regularly carried on between any two places is always advantageous, though not always equally so, to both[.]

—Adam Smith,

The Wealth of Nations (1776)

This thesis examines several aspects of China's foreign trade. We will investigate the causes for the rapid growth of foreign imports and also the consequences of conducting foreign trade.[1] To set the stage, we present a general picture about China's foreign trade growth and discuss its possible implications.

1.1 China's foreign trade: Stylized facts

China's total trade volume has grown from US$192 billion in 1993 to US$2,974 billion in 2010, which is a 17.5% compound annual growth rate for about two decades (details are given in Table A.1 in the Appendix). China's foreign trade is broken down into ordinary trade, processing trade,[2] and *the Remainder* (e.g., international aid flows, contracting projects, goods on lease, barter trade, other categories of trade flows). The breakdown has been applied to both foreign exports and foreign imports.

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[1] It, for example, poses a threat to China's trading partners, in particular to the United States (Autor et al., 2011).

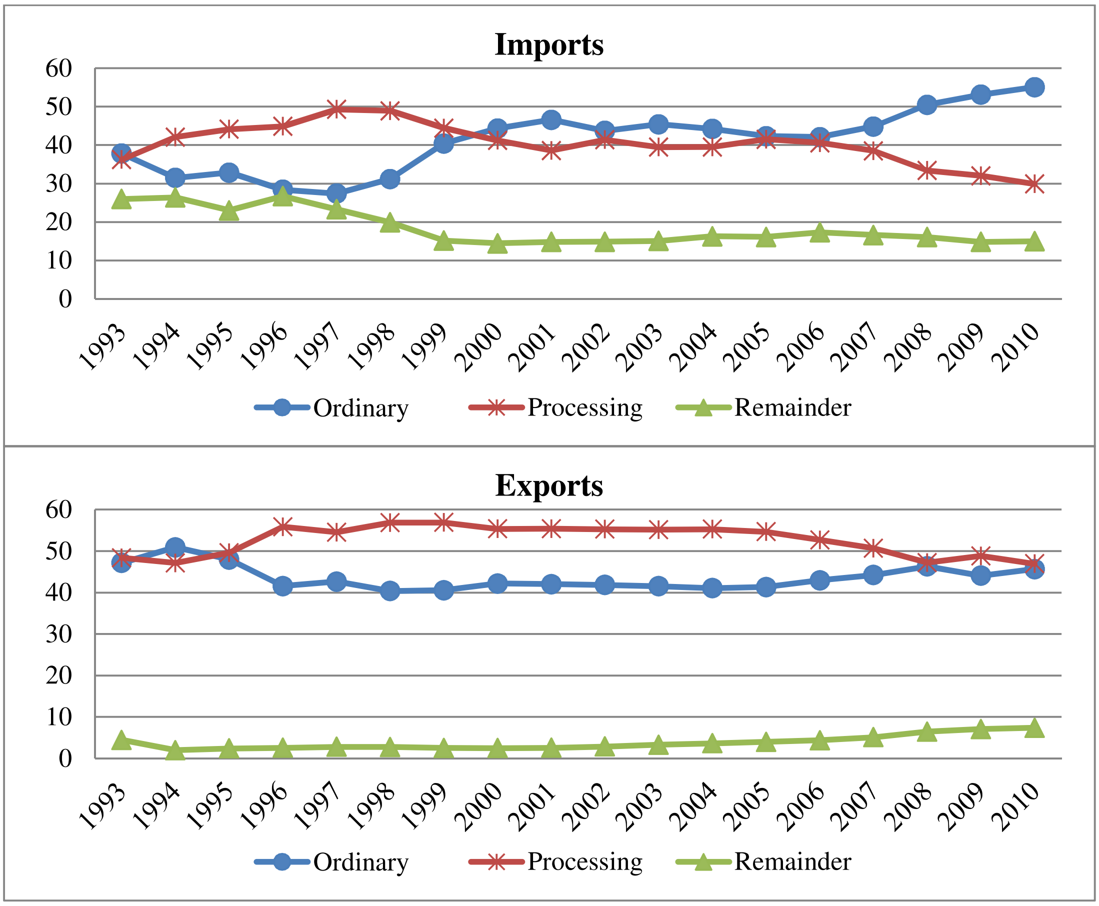
[2] Processing trade, as opposed to ordinary trade, involves importing inputs into China, which are processed or assembled there and then exported again (mainly by foreign-invested enterprises). Processing trade can be split into two types: processing with purchased import materials (PIM) and processing with customers' materials (PCM, or processing and assembling imports). In the case of PIM, which is the main type of processing trade, firms in China hold the import and export trading rights and use their own money to import materials. After processing or assembling, the goods are exported again by the company that holds those rights.

In the case of PCM, however, the foreign trading partner of the enterprise in China provides all or most of the materials. After simple assemble and processing, the finished products are shipped to the same foreign trading partner that supplied the materials. In this case, the enterprise in China only charges a processing fee and it does not purchase (i.e., import) materials or sell (i.e., export) products.

Consequently, in the case of PCM, only the value-added part is recorded, whereas the imported intermediate inputs of PCM are not included in the transaction part of the input-output (IO) table of China. They are, however, included in the imports and exports columns of the IO table because these data are obtained from Customs Statistics, which includes all processing trade.

For exports, ordinary exports and processing exports account for more than 92% of the total, while, for imports, the ordinary imports and processing imports make up roughly 80% of total imports (see Figure 1.1). As the upper panel of Figure 1.1 shows, the share of processing imports peaked in the year 1997/98 and has declined in relative importance since. Conversely, ordinary imports exceeded processing imports in 2000 and soared after 2006 when the share of processing imports began to contract sharply. In summary, ordinary imports took the lead in Chinese imports and see ever growing importance.

Figure 1.1 China's foreign trade shares by type: 1993-2010 (%)



In the lower panel of Figure 1.1, processing exports take the largest share for the whole period from 1993 to 2010 (except for 1994) and account for more than half of total exports from 1996 to 2007. It is clear that, in contrast with the case of imports in which ordinary imports had the largest share for the most years, processing exports determine roughly 50% of Chinese exports and have done so consistently for a long period.

1.2 Research questions addressed

Essentially, this thesis investigates the role of exports in the Chinese economy and includes four empirical studies. We examine (i) the role of exports in explaining imports, (ii) the role of exports in explaining value added (or income), (iii) the role of exports in various regions, and (iv) the effect of exports on emissions.

As shown previously, a crucial characteristic of China's exports is that processing trade plays a crucial role (i.e., approximately 50% of Chinese exports are processing exports) and therefore should be taken into account. Because processing exports typically require little domestic activity (and thus domestic inputs, domestic value added, and domestic emissions) and relatively many imported inputs, the failure to take this typical feature into account will bias the results. In this respect, this thesis presents some results that shed new light on previous findings.

It is widely believed that China's import growth has largely been driven by the growth of its exports (Koopman et al. 2008; Dean et al. 2011). Specifically, previous research has argued that China's growth of vertical specialization (Hummels et al., 2001), which refers to the import content in export products, supports the argument that China's import growth has been driven by the demand for export. However, as **Chapter 2** shows, the substantial increase of China's exports and the role of processing trade in the last decade only account for one-third of import growth. We will show empirically that Chinese import growth is mainly driven by the growth of domestic final demand rather than by its export growth.

Previous research also seems to suggest that exports, in particular those of "*high-tech*" industries, contribute much to China's value-added growth (Andreosso-O'Callaghan and Yue, 2002; Jiang, 2002; Guo, 2004; Li et al., 2005). In Chapter 3, two extended IO tables that explicitly distinguish processing trade from ordinary production for exports (Lau et al., 2007) have been used to discover the "truth" in this respect. Our findings in **Chapter 3** suggest that the contribution of the change in exports to value-added changes is 32% larger when the ordinary IO tables are used than when the appropriate extended IO tables are used. We also found that "sophisticated exports," such as *telecommunications*, are based on less domestic value added and much more foreign value added than might be expected. Furthermore, we argue that the methodology and the results may be relevant to other developing countries with considerable processing trade, such as Mexico (Johnson and Noguera, 2012).

Chapter 4 develops a methodology to decompose total national indirect income effects (induced by final demand) into intraregional income effects and interregional income spillover effects. The decomposition is applied to China's 2002 and 2007 interregional IO tables with processing and assembling exports separated from ordinary exports. The findings suggest that interregional income spillovers account for one-quarter to one-half of total national indirect income multipliers in 2007 and that the largest spillovers are found for the coastal regions. Moreover, a new measure—namely, "net interregional income spillovers"—is proposed to position China's individual regions in the production chains. This measure shows that upstream regions in the Center, Northwest, and Southwest of China are net recipients of interregional income spillovers generated by foreign exports in coastal regions. Over time, the production chains have become more pronounced.

Leontief (1970, pp. 262) states that "[pollution] is a by-product of regular economic activities. In each of its many forms it is related in a measurable way to some particular consumption or production process [.]" As the global economy becomes more integrated, one consequence is that pollution due to the production of exports has increased (e.g., 26% of global CO_2 emissions were caused by production for trade in 2008; Peters et al., 2011). The IO framework has been adopted to estimate the pollution generated by China's exports. Weber et al. (2008), for example, have estimated that roughly 21% of China's CO_2 emissions were due to exports in 2002 and thus "*on behalf of foreign consumers.*" This has become part of the debate as to whether China can and should be held accountable for all its emissions.

As mentioned previously, roughly half of China's exports are processing trade related to outsourcing. These exports generate relatively little value added, but also relatively little emissions. We argue in **Chapter 5** that existing estimates are overstated because processing exports have not been taken into account appropriately. By using an extended IO table, which distinguishes processing exports from ordinary exports, we show that Chinese exports are responsible for only 12.6% of Chinese CO_2 emissions.

To investigate these research questions, the input-output (IO) technique (Miller and Blair, 2009) will be employed because it enables investigation of both direct and indirect connections among economic units (i.e., industries, regions, and/or nations), on the one hand, and incorporation of external information, such as environmental data, on the other hand. More important, the IO methodology enables us to construct a consistent framework that explicitly separates processing trade from ordinary trade at industry level.

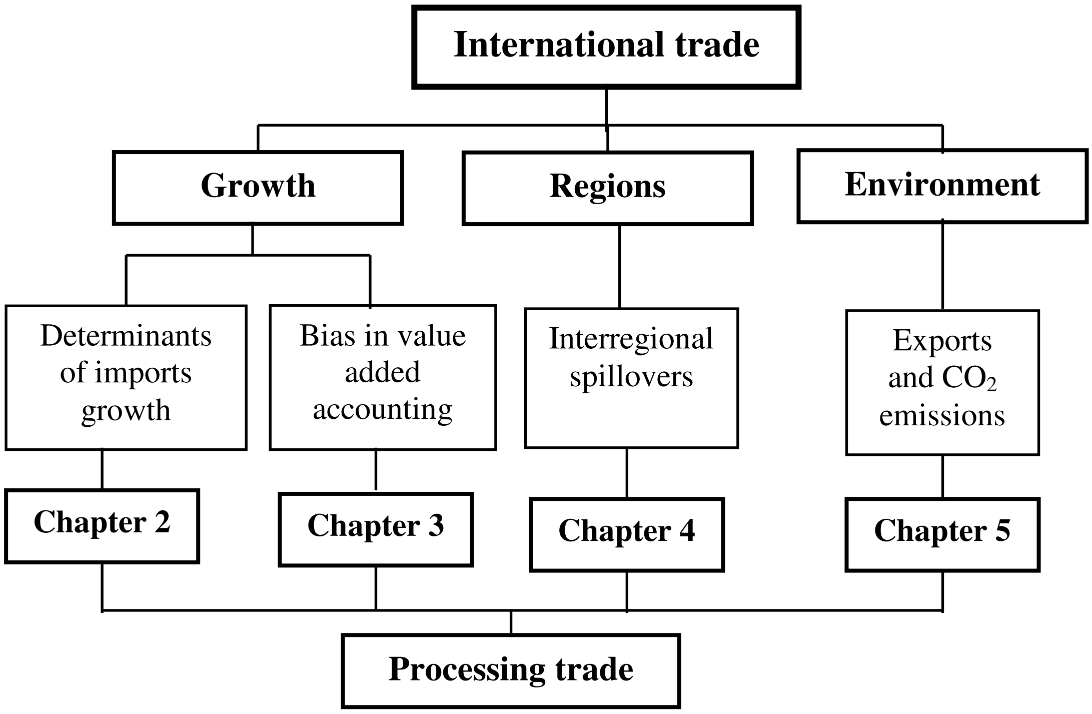
Therefore, the IO technique seems to be the appropriate methodology to address the research questions at both the aggregate and the industry level by connecting international trade (analyzing the determinants for China's import growth, Chapter 2), economic growth (both in a national context, Chapter 3, and in a regional context, Chapter 4), and environmental concerns (exports and CO_2 emissions, Chapter 5). Crucially, regarding the bias resulting from studies that overlook processing trade, this thesis provides an in-depth investigation that explicitly tackles processing trade.

1.3 Overview of the research

In Figure 1.2 a sketch of the thesis is given. For the sake of convenience and consistency, some general notations that are applied throughout the book are illustrated in the following:

By convention, matrices are given by bold, capital letters (say, $\mathbf{X}$); vectors by bold, lower case letters (say, $\mathbf{x}$); and scalars in italics, lower case letters (say, x). Vectors are column vectors by definition, a row vector is obtained by transposition which is indicated by a prime (say, $\mathbf{x}'$). $\hat{\mathbf{x}}$ indicates a diagonal matrix with the vector $\mathbf{x}$ on its main diagonal and *zero*s elsewhere.

Figure 1.2 A sketch of the thesis



Appendix

1.A China's foreign trade broken down by type: 1993-2010 (billion USD)

	Exports			Imports		
	Ordinary	Processing	Remainder	Ordinary	Processing	Remainder
1993	43.2	44.3	4.1	38.0	36.4	26.1
1994	61.6	57.0	2.4	35.5	47.5	29.8
1995	71.4	73.8	3.6	43.4	58.3	30.4
1996	62.8	84.3	3.9	39.4	62.3	37.1
1997	78.0	99.7	5.1	39.0	70.2	33.2
1998	74.2	104.5	5.1	43.7	68.6	27.9
1999	79.1	110.9	4.9	67.0	73.6	25.1
2000	104.8	137.5	6.2	99.5	92.5	32.4
2001	111.9	147.4	6.8	113.5	94.0	36.1
2002	136.2	180.0	9.4	129.1	122.2	43.9
2003	182.0	241.7	14.5	187.6	162.9	62.3
2004	243.6	328.0	21.7	248.1	221.7	91.4
2005	315.1	416.5	30.4	279.6	274.0	106.4
2006	416.2	510.4	42.4	333.1	321.4	137.0
2007	539.4	617.6	62.2	428.7	368.5	159.0
2008	662.9	675.2	92.6	572.1	378.4	182.1
2009	529.8	586.8	85.0	534.5	322.2	149.2
2010	720.6	740.3	116.9	769.3	417.5	209.4

CHAPTER 2

ACCOUNTING FOR CHINA'S IMPORT GROWTH: A STRUCTURAL DECOMPOSITION FOR 1997-2005[1]

2.1 Introduction

Recently, Martin Jacques (2009) published a book entitled "*When China Rules the World: The Rise of the Middle Kingdom and the End of the Western World*", in which he describes a world under a Pax Sinica.[2] It is true that China has become a major player in world trade, in particular after it was admitted as a member of the World Trade Organization (WTO) in 2001. Between 1997 and 2005, its imports increased by 296%.[3] In the same period, its exports increased only a little less, by 279%. This tremendous growth is sometimes interpreted as a threat to the rest of the world. However, China also has become an important link in the global supply chain, making it more dependent on other countries. Processing trade accounted for 51% of total exports in 2007.[4] This is also reflected by the sharp increase from 21% in 1997 to 30% in 2005 in overall vertical specialization (measured according to Hummels et al., 2001).[5] Both the rise in exports and its increasing integration into the global supply chain, as measured by the degree of vertical specialization, seems to suggest that China's import growth is largely export-driven (see also Koopman et al., 2008; Dean

[1] This chapter was originally published in *Environment and Plannning A*, vol. 43, pp. 2971-2991, 2011 (jointly written with Erik Dietzenbacher, Jan Oosterhaven and Cuihong Yang).

[2] It argues "[t]ime will not make China more Western; it will make the West, and the world, more Chinese" (see also the review "China's future: Enter the dragon" in *The Economist*, July 9, 2009).

[3] These imports and exports data are taken from China's input-output tables. Note that these data are not entirely consistent with the data published in China's Statistical Yearbooks, because the data in the input-output tables include not only trade of goods, but also trade of services. All prices in this chapter are expressed in 2000 constant prices, unless it is stated otherwise.

[4] Processing trade refers to the business activities of importing raw and auxiliary materials, parts and components, accessories, and packaging materials duty-free, and re-exporting the finished products after processing or assembling by enterprises within Mainland China. According to the official regulations, the goods imported duty-free (usually called processing imports) can only be used to produce goods that are exported (usually termed processing exports).

[5] In 1997, 1,000 Renminbi (RMB) of Chinese exports directly and indirectly required 214 RMB of imports, whereas the same 1,000 RMB of exports required 296 RMB of imports in 2005.

et al., 2008; Lawrence and Weinstein, 1999). This has fuelled the debate whether China's growth pattern is sustainable (Zheng et al., 2009).

A simple calculation with aggregate data, however, shows that increased exports and increased vertical specialization account for only 38% of the increase in imports between 1997 and 2005.[6] This implies that other factors must play a role (cf. Feenstra and Wei, 2009). Most importantly, real GDP per capita has risen with an average of 8.5% per year between 1997 and 2005. Thus, both total household consumption and its composition must have changed. Another factor that may have played a role is the change in production structure. As a transition economy, China has experienced substantial institutional and technological change. As Pack and Saggi (2006) argue, importing advanced technology and equipment as intermediate and investment goods leads to technology spillovers and contributes to increasing productivity (see also Lawrence and Weinstein, 1999). These sources and forms of growth in China's exports and imports are usually considered sustainable, as opposed to merely adding cheap labor to imported inputs and re-exporting the output (Amiti and Freund, 2008).

Analyzing the causes of growth in Chinese imports thus appears to be a non-trivial issue. It constitutes the aim of this chapter. First, the analysis should be able to capture the importance of the growth of the different components of macro economic demand, such as rural and urban household consumption, and exports. Secondly, the analysis should be able to capture the impact of the changes in the commodity composition of macro demand, which must have resulted from China's tremendous growth of GDP per capita. Third, the analysis must of course be able to capture the impact of the changes in production technology, which must have resulted from the modernization of Chinese industry. Finally, the impact of the growth of the import ratios of different commodities, due to the foreign opening up of the Chinese economy, must be accounted for.

To quantify the contribution of each of these different sources of import growth, we need to tackle the necessary input-output (IO) information with a structural decomposition analysis (SDA, see Rose and Casler, 1996, for an excellent overview). SDA can be viewed as an extension of growth accounting, as used in development

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[6] In fact, between 1997 and 2005, imports increased from 1,337 to 5,303 billion RMB. In the same period, exports grew from 1,661 to 6,293 billion RMB. Thus, a straightforward calculation, gives a ratio of $(0.296\times6{,}293 - 0.214\times1{,}661)/(5{,}303 - 1{,}337) = 0.38$.

economics, or shift-share analysis, as used in economic geography. It disentangles the change in one variable (i.e., imports) into the changes in its constituent parts.

In this chapter, using two specially prepared Chinese IO tables, we will be able to distinguish the changes in six macro-economic totals (rural household consumption, urban household consumption, government consumption, gross fixed capital formation, changes in stocks and inventories, and exports), the changes in the composition of each of these six totals, the changes in the technical input-output coefficients of the 32 sectors distinguished, and the changes in the import coefficients of these 32 industries' products. Given the remarkable growth of vertical specialization in China we also apply SDA to study its sources of growth.

The next section presents the basic data, describes the IO model used, discusses how we have processed the IO data, and presents a definition of vertical specialization adapted to the model used. Section 2.3 describes the basics of SDA, derives the formulas for decomposing vertical specialization and decomposing import growth, and derives a formula that shows how the growth of vertical specialization contributes to the growth of imports. Section 2.4 discusses the results for the decomposition of the changes of vertical specialization and import growth in China between 1997 and 2005, both at the aggregate level and at the 32-industry level, and compares our results with previous SDA studies. Section 2.5 summarizes the methodological innovations of the chapter, and concludes that the growth of domestic final demand is the single most important component in analyzing China's import growth, while changes in technology and changes in the composition of final demand are far more important for China than for other countries.

2.2 Data processing and model description

Our starting points are China's official constant price input-output (IO) tables for 1997 and 2005, constructed and maintained by the National Bureau of Statistics of China. Both tables are expressed in constant prices of 2000 and distinguish 62 sectors (see Liu and Peng, 2010). Given its importance for the problem at hand, it is paramount to reckon explicitly with the institutional phenomenon of "processing trade". Unfortunately, the IO data for processing trade for 1997 and 2005 are only available at a 42-sector classification scheme. Combining the two classifications resulted in two IO tables with 32 industries (see 2.A).

The structure of these tables is represented by Figure 2.1. Matrix **Z** gives the intermediate deliveries, both domestically produced as well as imported. Its element z_{ij} gives the purchases of worldwide product *i* (= 1, ..., *n*) by Chinese sector *j* (= 1, ..., *n*). Matrix **F** gives the final demands. Its element f_{ih} gives the purchases of product *i* (both domestically produced and imported) by Chinese final demand category *h* (= 1, ..., *k*). The vectors **e** and **m** denote the exports and imports of each product *i*. Vector **g** gives the changes in stocks and inventories, and vector **x** gives the domestic gross output of each sector. The (row) vector $\mathbf{v}'$ gives the value added of each sector, which comprises wages and salaries, capital depreciation, net taxes on production and the operating surplus.[7] The Chinese IO tables also include a column of statistical discrepancies, which is denoted by the vector $\boldsymbol{\varepsilon}$. The vector **s** is a summation vector (of appropriate length) consisting of ones.

Figure 2.1 Structure of the input-output table in China's official statistics

$\mathbf{Z}$	$\mathbf{F}$	$\mathbf{e}$	$\mathbf{g}$	$-\mathbf{m}$	$\boldsymbol{\varepsilon}$	$\mathbf{x}$
$\mathbf{v}'$	0	0	0	0	0	$\mathbf{v}'\mathbf{s}$
$\mathbf{x}'$	$\mathbf{s}'\mathbf{F}$	$\mathbf{s}'\mathbf{e}$	$\mathbf{s}'\mathbf{g}$	$-\mathbf{s}'\mathbf{m}$	$\mathbf{s}'\boldsymbol{\varepsilon}$	

To correctly estimate the Chinese direct and indirect imports due to its domestic final demand and its exports, domestically produced intermediate and final demands need to be separated from imported intermediate and final demands. Because more detailed information is lacking, it is assumed that the import coefficients are uniform along each row of the IO table. However, before we can apply this so-called proportional

[7] Vectors are columns by definition; rows are obtained by transposition, which is indicated by a prime.

method[8] some corrections need to be made for processing trade. There is a huge amount of processing trade in China, which can be split into two types: processing with imported materials (PIM) and processing with customer's materials (PCM).

PIM is the main type, accounting for more than 70% of the processing trade.[9] In the case of PIM, the Chinese enterprise that holds the import and export trading rights uses its own money to import materials. After processing or assembly, the goods are exported again by the company that holds those rights. In the case of PCM, however, the foreign trading partner of the Chinese enterprise provides all or most of the materials. The Chinese enterprise assembles and processes, after which the finished products are shipped to the same foreign trading partner that supplied the materials. In this case, the Chinese enterprise only charges a processing fee and it does not purchase (i.e., import) materials or sell (i.e., export) products. In terms of national accounting, the Chinese enterprise only reports the value-added part. Therefore, the imported intermediate inputs of PCM are not included in the transaction part of the IO table of China. They are, however, included in the imports and exports columns of the input-output table, because these data are obtained from Customs Statistics, which includes all processing trade.

Therefore, as a first step, we have to adjust the trade figures in the IO table. The trade flows connected to PCM can be viewed in exactly the same way as ordinary re-exports. Hence, we have subtracted these trade flows from both the imports and the exports column, as follows: $\overline{m}_i = m_i - m_i^{PCM}$ and $\overline{e}_i = e_i - m_i^{PCM}$. This results in an input-output table similar to that of Figure 2.1, but with $\overline{\mathbf{m}}$ replacing $\mathbf{m}$ and $\overline{\mathbf{e}}$ replacing $\mathbf{e}$.

Next, total imports (excluding PCM) needs to be subtracted from total intermediate and final demands, in order to estimate the domestically produced intermediate and final demands. To do that, it is assumed that a fixed share t_i is imported, while the rest is produced domestically, irrespective of the domestic destination of the product; further it is assumed that changes in stocks and inventories

[8] This method was also used by the Bureau of Economic Analysis to estimate the US import matrix for 1997, see http://www.bea.gov/industry/io_benchmark.htm#1997data. See Dervis et al. (1982) for an introduction, and Lahr (2001) for an overview of domestication techniques.

[9] See Table 5 "The Volumes of Exports and Imports Distinguished by Trade Types" (pp. 12) in China Customs Statistics, for various years. Note that the classification scheme in the Customs Statistics is the Harmonized System (HS). To aggregate the detailed HS data to IO sectors data, the concordance table of the National Bureau of Statistics of China is used.

are not imported, and that the statistical discrepancies are also not “imported”. Consequently, the demand by domestic producers and domestic final users is given by: $\mathbf{Zs}+\mathbf{Fs}=\mathbf{x}+\overline{\mathbf{m}}-\overline{\mathbf{e}}-\mathbf{g}-\boldsymbol{\varepsilon}$, while the import coefficients t_i are obtained as a share of this domestic demand. That is,

$$t_i = \frac{\overline{m}_i}{x_i + \overline{m}_i - \overline{e}_i - g_i - \varepsilon_i} = \frac{m_i - m_i^{PCM}}{x_i + m_i - e_i - g_i - \varepsilon_i} \tag{2-1}$$

or, in matrix notation, $\hat{\mathbf{t}} = (\hat{\mathbf{m}} - \hat{\mathbf{m}}^{PCM})(\hat{\mathbf{x}} + \hat{\mathbf{m}} - \hat{\mathbf{e}} - \hat{\mathbf{g}} - \hat{\boldsymbol{\varepsilon}})^{-1}$, where the hat indicates the diagonal matrix that is derived from the vector at hand. With (2-1) we can now estimate the IO table in Figure 2.2 as follows:

$$\mathbf{Z}^m = \hat{\mathbf{t}}\mathbf{Z}, \quad \mathbf{F}^m = \hat{\mathbf{t}}\mathbf{F}, \quad \mathbf{Z}^d = (\mathbf{I}-\hat{\mathbf{t}})\mathbf{Z}, \quad \mathbf{F}^d = (\mathbf{I}-\hat{\mathbf{t}})\mathbf{F} \tag{2-2}$$

Figure 2.2 Structure of the estimated input-output table that separates domestic flows from imports, excluding PCM

$\mathbf{Z}^d$	$\mathbf{F}^d$	$\overline{\mathbf{e}}$	$\mathbf{g}$	$\boldsymbol{\varepsilon}$	$\mathbf{x}$
$\mathbf{Z}^m$	$\mathbf{F}^m$	0	0	0	$\overline{\mathbf{m}}$
$\mathbf{v}'$	0	0	0	0	$\mathbf{v}'\mathbf{s}$
$\mathbf{x}'$	$\mathbf{s}'\mathbf{F}$	$\mathbf{s}'\overline{\mathbf{e}}$	$\mathbf{s}'\mathbf{g}$	$\mathbf{s}'\boldsymbol{\varepsilon}$	

Finally, in order to bring the import totals in line with the data given in the official IO table, we add the trade flows corresponding to PCM again as re-exports. This yields the IO table in Figure 2.3, which is the starting point for our analysis.

Figure 2.3 Structure of the estimated input-output table that separates domestic flows from imports, including PCM

$\mathbf{Z}^d$	$\mathbf{F}^d$	$\mathbf{e}-\mathbf{m}^{PCM}$	$\mathbf{g}$	$\boldsymbol{\varepsilon}$	$\mathbf{x}$
Z^m	$\mathbf{F}^m$	$\mathbf{m}^{PCM}$	0	0	$\mathbf{m}$
$\mathbf{v}'$	0	0	0	0	$\mathbf{v}'\mathbf{s}$
$\mathbf{x}'$	$\mathbf{s}'\mathbf{F}$	$\mathbf{s}'\mathbf{e}$	$\mathbf{s}'\mathbf{g}$	$\mathbf{s}'\boldsymbol{\varepsilon}$	

The accounting identities for total domestic production by sector now become:

$$\mathbf{x} = \mathbf{Z}^d\mathbf{s} + \mathbf{F}^d\mathbf{s} + \mathbf{g} + \mathbf{e} - \mathbf{m}^{PCM} + \boldsymbol{\varepsilon} = (\mathbf{I} - \hat{\mathbf{t}})\mathbf{Zs} + (\mathbf{I} - \hat{\mathbf{t}})\mathbf{Fs} + \mathbf{g} + \mathbf{e} - \mathbf{m}^{PCM} + \boldsymbol{\varepsilon} \qquad (2\text{-}3)$$

The technical input-output coefficients are defined as $a_{ij} = z_{ij} / x_j$, and reflect the input of product *i* (either domestically produced or imported) that is used per unit of domestic gross output of sector *j*. After substitution of $\mathbf{Z} = \mathbf{Ax}$, equation (2-3) can be solved as:

$$\mathbf{x} = [\mathbf{I} - (\mathbf{I} - \hat{\mathbf{t}})\mathbf{A}]^{-1}\ [(\mathbf{I} - \hat{\mathbf{t}})\mathbf{Fs} + \mathbf{g} + \mathbf{e} - \mathbf{m}^{PCM} + \boldsymbol{\varepsilon}] \qquad (2\text{-}4)$$

According to the imports part in Figure 2.3, we have $\mathbf{m} = \mathbf{Z}^m\mathbf{s} + \mathbf{F}^m\mathbf{s} + \mathbf{m}^{PCM}$ = $\hat{\mathbf{t}}\mathbf{Ax} + \hat{\mathbf{t}}\mathbf{Fs} + \mathbf{m}^{\mathrm{PCM}}$. Using equation (2-4), this yields the following solution for imports:

$$\mathbf{m} = \hat{\mathbf{t}}\mathbf{A}[\mathbf{I} - (\mathbf{I} - \hat{\mathbf{t}})\mathbf{A}]^{-1}[(\mathbf{I} - \hat{\mathbf{t}})\mathbf{Fs} + \mathbf{g} + \mathbf{e} - \mathbf{m}^{PCM} + \boldsymbol{\varepsilon}] + \hat{\mathbf{t}}\mathbf{Fs} + \mathbf{m}^{PCM} \qquad (2\text{-}5)$$

Vertical specialization (VS) is defined in Hummels et al. (2001) as the imported goods that are needed to produce a country's export goods. By regulation, the total amount of imports embodied in the PCM exports equals $\mathbf{s}'\mathbf{m}^{PCM}$. The total amount of imports embodied in other exports then equals the scalar

$\mathbf{t}'\mathbf{A}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}})\mathbf{A}]^{-1}(\mathbf{e}-\mathbf{m}^{PCM})$. The import content of the exports as a share of total exports, in our case, thus equals: $[\hat{\mathbf{t}}\mathbf{A}\{\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}})\mathbf{A}\}^{-1}(\mathbf{e}-\mathbf{m}^{PCM})+\mathbf{s}'\mathbf{m}^{PCM}]/\mathbf{s}'\mathbf{e}$.

Define the following vectors of shares: $\mathbf{b}^{e}=\mathbf{e}/\mathbf{s}'\mathbf{e}$, where b_i^e gives the share of product i in total exports, $\mathbf{b}^{PCM}=\mathbf{m}^{PCM}/\mathbf{s}'\mathbf{m}^{PCM}$, and b_i^{PCM} the share of product i in total PCM exports, and define $\mu=\mathbf{s}'\mathbf{m}^{PCM}/\mathbf{s}'\mathbf{e}$, where μ gives the share of PCM exports in total exports. Then vertical specialization in our particular data situation needs to be measured as:

$$VS=\mathbf{t}'\mathbf{A}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}})\mathbf{A}]^{-1}(\mathbf{b}^{e}-\mu\mathbf{b}^{PCM})+\mu \qquad (2\text{-}6)$$

2.3 Structural decomposition analysis

Structural decomposition analysis (SDA) is widely used to study economic changes over time within an input-output framework. In essence, it decomposes the change in some endogenous variable into the changes in its constituent exogenous parts. SDA has been applied to a broad range of topics, including value added changes from an intercountry perspective (Oosterhaven and Hoen, 1998), consumption growth (Dietzenbacher et al., 2007), labor productivity (Dietzenbacher et al., 2000; Oosterhaven and Broersma, 2007), labor compensation (Dietzenbacher et al., 2004) and various environment and energy related issues (Diakoulaki and Mandaraka, 2007; Guan et al., 2009; Kagawa et al., 2008; Wing, 2008; Zhang, 2009).

In its simplest form with two sources of change we have **U** = **VW**, while we would like to decompose the changes in **U** into changes in **V** and **W**. Writing $\Delta U=U_1-U_0=V_1W_1-V_0W_0$, two decompositions are possible:

$$\Delta U=(V_1-V_0)W_1+V_0(W_1-W_0)=(\Delta V)W_1+V_0(\Delta W)$$
$$\Delta U=(V_1-V_0)W_0+V_1(W_1-W_0)=(\Delta V)W_0+V_1(\Delta W)$$

This simple example indicates that decompositions are not unique, because we have two different forms, which have two different economic meanings. In a growing economy, the first decomposition overestimates the contribution of ΔV and underestimates the contribution of ΔW, whereas the second decomposition does the opposite (cf. the *Laspeyres* and *Paasche* price and volume indices, see Skolka, 1989, for a further discussion). Hence, taking the average is the obvious theoretically preferred solution.

Dietzenbacher and Los (1998) show that when the variable under consideration is obtained from the multiplication of n other variables, we have $n!$ equivalent decomposition forms. Empirically they also show that the average of all $n!$ forms can be approximated very well by the average of two specific forms, the so-called polar decompositions (see Oosterhaven and van der Linden, 1997, for a first application). Subsequently, de Haan (2001) showed that the average of any couple of mirrored decompositions provides a good approximation.

Hence, in our case, both for theoretical and for empirical reasons, we also take the average of two mirrored decompositions. For the VS measure in (2-6) we have five sources of change: **t**, **A**, $\mathbf{b}^e$, $\mathbf{b}^{PCM}$ and μ. One possibility for decomposing the change between 1997 and 2005 yields:

$$\Delta VS =$$

$$\mathbf{t}'_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}(\mathbf{b}^e_{05}-\mu_{05}\mathbf{b}^{PCM}_{05})-\mathbf{t}'_{05}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{97}]^{-1}(\mathbf{b}^e_{05}-\mu_{05}\mathbf{b}^{PCM}_{05}) \quad \text{(2-7a)}$$

$$+\mathbf{t}'_{05}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{97}]^{-1}(\mathbf{b}^e_{05}-\mu_{05}\mathbf{b}^{PCM}_{05})-\mathbf{t}'_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}(\mathbf{b}^e_{05}-\mu_{05}\mathbf{b}^{PCM}_{05}) \quad \text{(2-7b)}$$

$$+\mathbf{t}'_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}\mathbf{b}^e_{05}-\mathbf{t}'_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}\mathbf{b}^e_{97} \quad \text{(2-7c)}$$

$$-\mathbf{t}'_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}\mu_{05}\mathbf{b}^{PCM}_{05}+\mathbf{t}'_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}\mu_{05}\mathbf{b}^{PCM}_{97} \quad \text{(2-7d)}$$

$$+\mu_{05}-\mathbf{t}'_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}\mu_{05}\mathbf{b}^{PCM}_{97}-\mu_{97}+\mathbf{t}'_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}\mu_{97}\mathbf{b}^{PCM}_{97} \quad \text{(2-7e)}$$

Expression (2-7a) gives the change in *VS* that would have occurred when only the technical coefficients (i.e., **A**) would have changed, while the other variables (i.e., **t**, $\mathbf{b}^e$, $\mathbf{b}^{PCM}$ and μ) take their 2005 values. The mirror image of expression (2-7a) is obtained below by assuming that the other variables take their 1997 values.

Expression (2-7b) measures the effect of changing the import shares **t**, leaving the other variables (i.e., **A**, $\mathbf{b}^e$, $\mathbf{b}^{PCM}$ and μ) fixed. Its mirror image is obtained by changing 05 into 97 (and vice versa) for all variables, except for **t**. The mirror images of expressions (2-7c)–(2-7e) are obtained in the same fashion. Combining the mirror images of (2-7) gives the second, mirror decomposition of the change in vertical specialization:

$$\Delta VS =$$

$$\mathbf{t}'_{97}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{05}]^{-1}(\mathbf{b}^e_{97}-\mu_{97}\mathbf{b}^{PCM}_{97})-\mathbf{t}'_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}(\mathbf{b}^e_{97}-\mu_{97}\mathbf{b}^{PCM}_{97}) \quad \text{(2-8a)}$$

$$+\mathbf{t}'_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}(\mathbf{b}^e_{97}-\mu_{97}\mathbf{b}^{PCM}_{97})-\mathbf{t}'_{97}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{05}]^{-1}(\mathbf{b}^e_{97}-\mu_{97}\mathbf{b}^{PCM}_{97}) \quad \text{(2-8b)}$$

$$+\mathbf{t}'_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}\mathbf{b}^e_{05}-\mathbf{t}'_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}\mathbf{b}^e_{97} \quad \text{(2-8c)}$$

$$-\mathbf{t}'_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}\mu_{97}\mathbf{b}^{PCM}_{05}+\mathbf{t}'_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}\mu_{97}\mathbf{b}^{PCM}_{97} \quad \text{(2-8d)}$$

$$+\mu_{05}-\mathbf{t}'_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}\mu_{05}\mathbf{b}^{PCM}_{05}-\mu_{97}+\mathbf{t}'_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}\mu_{97}\mathbf{b}^{PCM}_{05} \quad \text{(2-8e)}$$

Equations (2-7a) and (2-8a) each measure the change in *VS* due to changes in the technical coefficients **A**, but the changes are weighted differently. The final Δ**A**-effect is obtained by taking the average of expressions (2-7a) and (2-8a). In the same way, the other four effects are defined. The five effects together exactly account for the actual change in *VS*.

Note that, we can disaggregate the measure for vertical specialization to the sectoral level by using the diagonal matrix with import ratios $\hat{\mathbf{t}}$. Equation (2-6) for *VS* then becomes:

$$\mathbf{VS}=\hat{\mathbf{t}}\mathbf{A}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}})\mathbf{A}]^{-1}(\mathbf{b}^e-\mu\mathbf{b}^{PCM})+\mu\mathbf{b}^{PCM} \quad \text{(2-9)}$$

This aggregates back to *VS*, since $VS=\mathbf{s}'\mathbf{VS}$. In interpreting (2-9), suppose first that *PCM* equals zero, i.e. $\mu = 0$. Then, the *i*th element of the vector **VS** gives the imports of product *i* that are necessary for 1 RMB of total exports. In case $\mu > 0$, 1 RMB of total exports includes somewhat less than 1 RMB of "ordinary" exports plus some amount of *PCM* exports. These "ordinary" exports induce imports of product *i*, as given by the first term on the right-hand side of (2-10), to which the *PCM* imports are added to yield the total imports of product *i*. The reason for this difference in treatment is that *PCM* imports generate no value added and do not enter the production process. Instead they are similar to re-exports, and therefore they are equal to *PCM* exports.

In order to analyze *import growth* and to measure the contributions of its sources of change, we also apply SDA to equation (2-5), which includes seven sources, $\mathbf{t}$, $\mathbf{A}$, $\mathbf{F}$, $\mathbf{e}$, $\mathbf{m}^{PCM}$, $\mathbf{g}$ and $\boldsymbol{\varepsilon}$. Moreover, we would like to explicitly distinguish between the change in the total of a certain final demand category and the change in its composition by products. For the exports, we already defined $\mathbf{b}^e = \mathbf{e}/\mathbf{s}'\mathbf{e}$, where $\mathbf{s}'\mathbf{e}$ indicates total exports. This implies that we can write $\mathbf{e} = (\mathbf{s}'\mathbf{e})\mathbf{b}^e = \sigma^e\mathbf{b}^e$ where σ^e gives the total exports and $\mathbf{b}^e$ the export pattern. The same applies for the changes in stocks and inventories, i.e. $\mathbf{g} = (\mathbf{s}'\mathbf{g})\mathbf{b}^g = \sigma^g\mathbf{b}^g$ with $\mathbf{b}^g = \mathbf{g}/\mathbf{s}'\mathbf{g}$, and for PCM imports, i.e. $\mathbf{m}^{PCM} = (\mathbf{s}'\mathbf{m}^{PCM})\mathbf{b}^{PCM} = \boldsymbol{\sigma}^{PCM}\mathbf{b}^{PCM}$. In the same fashion, dividing all elements of the matrix $\mathbf{F}$ by their corresponding column sums gives the pattern of final demands in the so-called bridge matrix $\mathbf{B}$ (cf. Feldman et al., 1987). That is, $b_{ih} = f_{ih} / \Sigma_{j=1}^{n} f_{jh}$ gives the share of total final demand in category *h* (e.g., rural household consumption) that is spent on product *i*. Let us write $(\boldsymbol{\sigma}^F)' = \mathbf{s}'\mathbf{F}$ for the row vector of final demand totals. Then equation (2-5) is further detailed as:

$$\mathbf{m} = \hat{\mathbf{t}}\mathbf{A}[\mathbf{I} - (\mathbf{I} - \hat{\mathbf{t}})\mathbf{A}]^{-1}[(\mathbf{I} - \hat{\mathbf{t}})\mathbf{B}\boldsymbol{\sigma}^F + \mathbf{b}^e\sigma^e - \mathbf{b}^{PCM}\sigma^{PCM} + \mathbf{b}^g\sigma^g + \boldsymbol{\varepsilon}] + \hat{\mathbf{t}}\mathbf{B}\boldsymbol{\sigma}^F + \mathbf{b}^{PCM}\sigma^{PCM} \tag{2-10}$$

This expression has 17 sources of change. First, 9 types of model coefficients, namely import shares ($\mathbf{t}$), technical coefficients ($\mathbf{A}$), composition of 4 types of final demand ($\mathbf{B}$), composition of ordinary exports ($\mathbf{b}^e$), composition of PCM exports ($\mathbf{b}^{PCM}$) and the composition of changes in stocks and inventories ($\mathbf{b}^g$). Second, 7 types of macro-economic totals, namely 4 types of domestic final demand ($\boldsymbol{\sigma}^F$), total ordinary exports (σ^e), total PCM exports (σ^{PCM}) and total changes in stocks and inventories (σ^g). And, finally, one column with statistical discrepancies ($\boldsymbol{\varepsilon}$). The decomposition of equation (2-10) is given in 2.B.

Finally, to relate the import growth to the growth of vertical specialization, equation (2-9) is combined with equation (2-10), which yields:

$$\begin{aligned}
\mathbf{m} &= \hat{\mathbf{t}}\mathbf{A}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}})\mathbf{A}]^{-1}(\mathbf{b}^e\sigma^e - \mathbf{b}^{PCM}\sigma^{PCM}) + \mathbf{b}^{PCM}\sigma^{PCM} \\
&\quad + \hat{\mathbf{t}}\mathbf{A}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}})\mathbf{A}]^{-1}[(\mathbf{I}-\hat{\mathbf{t}})\mathbf{B}\boldsymbol{\sigma}^F + \mathbf{b}^g\sigma^g + \boldsymbol{\varepsilon}] + \hat{\mathbf{t}}\mathbf{B}\boldsymbol{\sigma}^F \\
&= \hat{\mathbf{t}}\mathbf{A}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}})\mathbf{A}]^{-1}(\mathbf{b}^e\sigma^e - \mathbf{b}^{PCM}\sigma^{PCM}) + \mathbf{b}^{PCM}\sigma^{PCM} + \mathbf{q} \\
&= \hat{\mathbf{t}}\mathbf{A}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}})\mathbf{A}]^{-1}(\mathbf{b}^e - \mu\mathbf{b}^{PCM})\sigma^e + \mu\mathbf{b}^{PCM}\sigma^e + \mathbf{q} \\
&= \mathbf{VS}\cdot\sigma^e + \mathbf{q}
\end{aligned} \tag{2-11}$$

where $\mathbf{q} = \hat{\mathbf{t}}\mathbf{A}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}})\mathbf{A}]^{-1}[(\mathbf{I}-\hat{\mathbf{t}})\mathbf{B}\boldsymbol{\sigma}^F + \mathbf{b}^g\sigma^g + \boldsymbol{\varepsilon}] + \hat{\mathbf{t}}\mathbf{B}\boldsymbol{\sigma}^F$ and $\mathbf{b}^{PCM}\sigma^{PCM} = \mathbf{m}^{PCM} = \mu\mathbf{b}^{PCM}\sigma^{\mathrm{e}}$. Equation (2-11) shows that the imports of good *i* are equal to the product of the vertical specialization effect for good *i* and the total exports, plus other terms that are all related to domestic final demands. Consequently, we can now also calculate the contribution of a change in vertical specialization to the import growth of product *i*, using the following decomposition:

$$\Delta\mathbf{m} = \tfrac{1}{2}(\Delta\mathbf{VS})(\sigma_{97}^e + \sigma_{05}^e) + \tfrac{1}{2}(\mathbf{VS}_{97} + \mathbf{VS}_{05})(\Delta\sigma^e) + \Delta\mathbf{q} \tag{2-12}$$

2.4 Empirical results

First, we discuss the empirical results of the decomposition of the growth in vertical specialization (VS) with (2-9). It appears that the growth of import shares contributes 53% of the total growth of VS. Second, we determine the contribution of VS and export growth to total import growth with (2-12), which is shown to amount to only 38%. Third, we discuss the total of all factors that contribute to the growth of imports at the aggregate level with (2-10), and compare these outcomes with previous structural decomposition analyses. Fourth, we discuss the decomposition results at the level of the imports of individual types of products.

2.4.1 Decomposition of the growth in vertical specialization

China's vertical specialization has grown more than 8% points within one decade, as the (direct and indirect) import content of 100 RMB of exports increased from 21.4 RMB in 1997 to 29.6 RMB in 2005 (see Table 2.1). This is much faster than the merely 4.6% points increase in the VS measure for the 14-economies sample for the two decades of 1970 (roughly 16.5%) to 1990 (about 21.1%) that was reported in Hummels et al. (2001). Clearly, China has integrated into the global supply chain must faster than these other economies.

Table 2.1 Decomposition of the growth in vertical specialization for China, 1997-2005

Vertical specialization*		Contribution of the effects					
1997	2005	Growth	$\Delta\mathbf{A}$	$\Delta\mathbf{t}$	$\Delta\mathbf{b}^e$	$\mathbf{b}^{PCM}$	μ
21.43	29.62	8.20 (100%)	1.77 (22%)	4.36 (53%)	4.14 (50%)	-0.51 (-6%)	-1.56 (-19%)

* RMB of imports per 100 RMB of exports.

With equation (2-9), the change in vertical specialization can be decomposed into five components (see Table 2.1). The component with the largest contribution of 53% to the total VS growth is the $\Delta\mathbf{t}$-effect. That is, if only the direct imports shares would have changed, the growth in vertical specialization would have been 4.4% point. It turns out that the average import share has risen from 6.9% in 1997 to 11.3% in 2005 (which accidentally is also an increase of 4.4% point). In particular, the import shares of manufacturing products show a strong increase. This is very much in line with the role that processing trade (and the importance of manufacturing therein) plays in vertical specialization.

The changes in the export pattern (the $\Delta\mathbf{b}^e$-effect) provide the second largest contribution, and account for 50% of the total increase in VS of 8.2% point. This finding indicates that the export pattern has changed such that import-intensive exports have gained more weight. This is in line with the importance of processing trade for China's exports and its increase over time to 51% in 2007.

The third largest component is the change in the technical coefficients (the $\Delta\mathbf{A}$-effect), accounting for 22% of the total increase in VS. This effect indicates an increased use of intermediate inputs, and hence of imports, especially in the exporting industries. In fact, the weighted average of the column sums of the **A** matrix (calculated as the total of all intermediate input use over the total of all gross outputs) has increased from 0.59 in 1997 to 0.65 in 2005. This implies that the weighted average of the value added coefficients has decreased from 0.41 to 0.35. These changes are again in line with the increased importance of processing trade for China's exports.

Each of the three components sketches an element of the crucial role that processing trade plays in China's vertical specialization: (i) it increases the dependence on imported inputs, in particular manufacturing products; (ii) it increases the importance of intermediate inputs relative to that of value added; and (iii) it shifts the export pattern towards more import-intensive products.

2.4.2 Vertical specialization and import growth

Although vertical specialization may be important in determining the imports of China, it is only part of the story. Here we focus on the relative importance of increased vertical specialization on import growth, both for individual products and for the total.

The results of the decomposition equation (2-12) are given in Table 2.2.[10] The bottom row gives the totals and corresponds to the calculation at the aggregate level discussed in Section 2.4.1. It shows that the increase in vertical specialization and the growth in total exports together account for only 38% of the growth in total imports, whereas 62% of the total import growth stems from other sources of change.

The detailed results in Table 2.2 show a huge variation across industries. Telecommunication equipment, computer and other electronic equipment products (industry 19) show by far the largest absolute growth of imports of 1,201 billion RMB (in 2000 prices). This accounts, with 288 billion RMB, for more than four-fifth of the total contribution of VS to Chinese import growth, of 326 billion RMB.

[10] Note that three sectors, water production and supply (sector 24), wholesale and retail trade (28), and real estate (31), are lacking. Products of these sectors werenot imported, neither in 1997 nor in 2005, and consequently Table 2.2 would have only show zeros in their rows.

Table 2.2 Decomposition of Chinese import growth and the role of vertical specialization*

Sector	Import growth (billion RMB)	ΔVS		$\Delta\sigma^e$		Δq	
		bRMB	%	bRMB	%	bRMB	%
1	78	-4	-6	19	25	62	81
2	6	1	14	1	15	5	71
3	187	18	10	61	32	108	58
4	154	20	13	37	24	97	63
5	29	7	23	8	28	14	48
6	42	-6	-13	14	32	34	81
7	65	-47	-72	91	140	21	32
8	21	-22	-106	30	141	14	65
9	12	-3	-22	7	60	8	62
10	53	-14	-27	37	70	30	57
11	48	0	1	21	44	26	55
12	354	-41	-11	188	53	207	58
13	18	-1	-4	5	27	14	77
14	177	3	2	68	39	105	59
15	47	-5	-10	22	46	30	64
16	298	0	0	55	19	242	81
17	122	4	4	19	16	98	81
18	233	24	10	55	23	154	66
19	1,201	288	24	320	27	593	49
20	487	81	17	84	17	322	66
21	49	-1	-1	14	28	36	73
22	2	0	18	0	11	1	72
23	0	0	16	0	-9	0	94
25	6	0	1	0	1	6	98
26	58	7	12	8	14	43	74
27	0	0	6	0	22	0	71
29	70	5	7	7	9	59	84
30	27	2	8	3	12	22	80
32	122	7	6	9	8	106	87
Total	3,965	326	8	1,182	30	2,457	62

*bRMB gives the contribution in billion RMB (in 2000 constant price), % gives the contribution as a percentage of the total import growth in the corresponding row.

However, even for this industry vertical specialization accounts for only 24% of the import growth of its own products, while total Chinese export growth accounts for another 27% of this import growth. Hence, while processing trade is relatively important for this sector, it still accounts for hardly half of its import growth.

Moreover, for all other products the contribution of VS to import growth is less than the 24% for sector 19 products.

Looking further at the role of total exports, it appears that the growth of imports of textile (industry 7), wearing apparel, leather etc. (8), paper, printing and record media products (10), sawmills and furniture (9) and chemicals (12) may be attributed for by more than half to the growth of total exports. However, for almost all of these products, and especially for wearing apparel, leather etc. (8) and textile goods (7), the contribution of vertical specialization to their import growth is actually negative (-106% and -72%, respectively). These negative values indicate a reduction of the dependence on imports, or equivalently more self-reliance, for the exports of these traditional industries.

Consequently, for the majority of the products, the growth of their import needs to be attributed to other factors than the growth of vertical specialization or of total exports. Given the large weight of the imports of products of sector 19, which are accounted for more than half by VS-growth and export growth, the import growth of roughly half of the other sectors' products is accounted for 70% or more by other factors, which we will discuss next.

2.4.3 Decomposing the growth of total imports

Here we discuss the further decomposition of the growth of total imports with the formulas given in 2.B. We have combined the effects of the 4 components of domestic final demand, and we do not show the very small non-zero impacts of statistical discrepancies $\Delta\boldsymbol{\varepsilon}$, as they are meaningless. Neither do we show the impacts of the total change in stocks $\Delta\sigma^g$, which is zero. The impacts of the change in the composition of the changes in stocks $\Delta\mathbf{b}^g$ are small but not negligible. They are presented in Table 2.3 for completeness sake, but they do not have a sensible economic interpretation either.

The findings for the aggregate Chinese import growth are given in the one but last row (indicated by %) of Table 2.3. The first (but perhaps not surprising) finding is the relatively large contribution of the change in the import ratios $\Delta\mathbf{t}$. The average import ratio has increased from 6.9% in 1997 to 11.3% in 2005. This is only partly explained by the growth in vertical specialization.

Table 2.3 Detailed decomposition of Chinese import growth, 1997-2005*

CODE	Import growth (bRMB)	Percentage contribution of effects								
		Changes in coefficients						Changes in levels		
		$\Delta\mathbf{A}$	$\Delta\mathbf{t}$	$\Delta\mathbf{B}$	$\Delta\mathbf{b}^g$	$\Delta\mathbf{b}^{PCI}$	$\Delta\mathbf{b}^e$	$\Delta\boldsymbol{\sigma}^F$	$\Delta\sigma^{PCM}$	$\Delta\sigma^e$
1	78	2	63	-37	4	-6	-5	52	4	19
2	6	1	57	0	-1	0	0	27	-1	16
3	187	11	30	-1	-3	-2	-2	37	3	28
4	154	12	46	0	-1	-6	2	27	3	20
5	29	0	39	-7	-1	19	0	24	17	8
6	42	15	12	-15	4	-7	-5	65	13	16
7	65	-31	14	1	0	-33	-11	32	63	60
8	21	10	-72	35	3	-70	-5	78	84	33
9	12	31	-24	-19	-7	-18	4	81	24	29
10	53	22	-26	1	-1	-17	-1	55	23	41
11	48	24	-44	-2	-3	0	1	83	-3	47
12	354	2	16	-1	-2	-12	0	43	11	39
13	18	20	-8	-13	0	-7	4	81	8	16
14	177	14	3	0	-1	-5	5	50	8	29
15	47	-26	17	2	-1	-11	6	70	12	30
16	298	-1	-8	10	0	0	2	79	0	19
17	122	13	7	4	3	-1	2	55	0	16
18	233	3	35	4	0	0	4	31	7	15
19	1,201	12	14	10	1	5	10	20	5	21
20	487	11	28	10	0	10	1	23	8	8
21	49	-2	55	1	-1	-9	1	31	10	15
22	2	16	54	0	-1	0	0	19	-1	12
23	0	-32	235	-44	0	0	-1	-49	1	-10
25	6	6	-10	-26	0	0	0	128	0	2
26	58	20	33	4	-1	0	0	30	-1	15
27	0	39	-44	12	-1	0	-1	71	-1	24
29	70	7	42	9	-1	0	0	33	-1	10
30	27	-20	71	7	0	0	0	30	-1	13
32	122	19	17	11	0	0	0	45	-1	8
Total	3,965	333	711	205	1	-16	146	1,445	275	842
%	100	8	18	5	0	0	4	36	7	21
abs%	100	9	18	6	1	5	4	31	6	18

* (1) The totals are in billion RMB, and are not the simple column sums (except for the column with import growth). (2) The impacts of statistical discrepancies and of the total change in stocks are not listed. Consequently, the percentages in the rows do not add to 100.

Comparably important is the increase in the use of imported goods by domestic final users (i.e., consumers, the government and investors). Together these two factors lead to the contribution of 18% of increasing import ratios to the aggregate import growth.[11]

The role of the changes in the composition of final demands ($\Delta\mathbf{B}$) and the composition of exports ($\Delta\mathbf{b}^e$) is rather limited (5% and 4%, respectively). In the case of the export pattern changes, this matches the results from Tables 2.1 and 2.2. That is, the changes in the export pattern account for 50% of the change in vertical specialization, which in its turn contributes 8% of the growth in total imports. This suggests a contribution of 4% to total import growth.

A similar conclusion does not apply to the contribution of the changes in the technical coefficients ($\Delta\mathbf{A}$). It contributes 22% of the change in vertical specialization, which would yield a 2% contribution to import growth. As can be seen in equation (2-11), however, the changes in technical coefficients also impact import growth via another route, i.e. via $\Delta\mathbf{q}$. The actual 8% contribution of $\Delta\mathbf{A}$ to import growth found in Table 2.3 is quite considerable and indicates that the Chinese production structure has witnessed changes that seriously affected import growth. Changes in technical input-output coefficients are a determinant that is present in almost all structural decomposition analyses. The typical finding (in particular for developed countries) is that their contribution is very small, indicative of little change or a slowly evolving production structure. The result for China is therefore quite remarkable.

Note that half of the determinants are changes in shares (which sum to one) or changes in ratios. In Table 2.3, they have been grouped as changes in "coefficients". Next to the statistical discrepancies, the other components represent changes in levels of exogenous variables. In decompositions where the change in a certain variable in levels is decomposed into the changes due to coefficient changes and changes due to changes in levels, the typical finding is that the changes in levels account for almost the full 100%. The third remarkable finding is that this is not the case for China. In decomposing the growth of total imports in China, the changes in "levels" contribute only 65%, leaving 35% for the changes in "coefficients".

[11] Note that, as pointed by one referee, the increase in import shares probably is concentrated in the coastal provinces (in particular in the Guangdong Province), where processing trade production is relatively cost-effective. In general, the phenomena studied here will not only exhibit large sectoral differences, as shown in the Tables 2.2 and 2.3, but also large spatial differences, which can only be studied with two comparable full interregional IO tables.

To substantiate this claim of remarkability, we have compared our result with previous research. We have grouped the SDA results of previous studies into the same two categories, as is done in Table 2.3. The research papers listed in Table 2.4 are taken from *Econ Lit* after a search with the keyword "structural decomposition analysis". Some papers in the original sample have been discarded, either because they did not contain an empirical analysis or because they did not provide the details necessary to make the distinction between "coefficients" and "levels".

Table 2.4 Comparison with previous structural decomposition analyses

Dependent variable	Input-output data	Period	% contribution		Study
			Coeff.s	Levels	
Value added	Intercountry EU	1985-1995	-3.4	103.4	Los &Oosterhaven (2008)
Output	China	1987-1997	17.2	82.8	Andreosso-O'Callaghan&Yue (2002)
Output	India	1983/84-1989/90	3.5	96.5	Roy et al. (2002)
Value added	The Netherlands	1972-1986	-13.2	113.2	Dietzenbacher& Los (2000)
Output	South Africa	1975-1993	28.4	71.6	Liu &Saal (2001)
Output	Chile	1960-1990	8.0	92.0	Albala-Bertrand (1999)
Output	China	1987-1992	29.3	70.7	Liu (1998)
Value added (nominal)	Intercountry EU	1975-1985	-2.3	102.3	Oosterhaven & van der Linden (1997)
Value added (real)	Intercountry EU	1975-1985	-3.4	103.4	Oosterhaven&Hoen (1998)
Output	Austria	1964-1976	26.4	73.6	Skolka (1989)
Employment	Austria	1964-1976	33.8	66.2	Skolka (1989)
Average			11.3	88.7	

It is clear from Table 2.4 that the changes in the levels of the exogenous variables play indeed a dominant role. An important part of the explanation is that both categories ("levels" and "coefficients") represent aggregates of underlying components. At the industry level, the contribution of each of the components underlying the aggregate category "levels" almost always has the same (positive) sign.

In contrast, the contributions of the components underlying the aggregate category "coefficients" often have opposite signs at the industry level and, as a consequence, they cancel each other. Table 2.4 shows that this canceling may be substantial given the average of only an 11% contribution for the total of the coefficients changes. The 35% that we have found for China in Table 2.3 is therefore exceptionally high.

Similar outcomes are the 28% contribution of the coefficient changes to the output growth in China for the period 1987-1992 (Liu, 1998), and the 17% contribution of coefficient changes to Chinese output growth for the period 1987-1997 (Andreosso-O'Callaghan and Yue, 2002). Other cases where changes in coefficients contribute a relatively large part, have been found for South Africa (Liu and Saal, 2001), and for Austria (Skolka, 1989). What is common to all cases is that for each of the countries, the period under consideration reflects a phase of rapid restructuring. That is, drastic changes are observed in the production structure, in the commodity composition of expenditures by consumers, governments and investors, in the mix of exports, or in the import dependence ratios. This explains why for restructuring economies a relatively large contribution is found for the contribution by "coefficients".

2.4.4 Decomposition of import growth at the industry level

The aggregate contributions to total import growth (as shown in the last but one row of Table 2.3 and discussed in the previous subsection) hide large variations in contributions to the growth of imports at the levels of individual products, which are shown in the other rows of Table 2.3.[12]

Again, we first look at the contribution of the *changes in coefficients*. The decrease of the import coefficients $\Delta\mathbf{t}$ is by far the most important component in this domain. Of the five industries with the largest growth of imports (i.e., 12, 16, 18, 19 and 20), only two (electric equipment and machinery, 18, and instruments and office machinery, 20) have an increase of their import coefficient that contributes more than 28% of the total rise in the imports of their products. The single largest contribution of 235% in the case of gas production and supply (23) has little meaning,

[12] Note that the effects of the change in total exports (i.e., $\Delta\sigma^e$) on import growth slightly differ between Tables 2.2 and 2.3. This is the result of a different weighting, as can be seen in equations (2-10) and (2-11).

as it is caused by dividing the impact of the increase of its import coefficient by the total increase in its imports of only 16 thousand RMB (i.e., 0 billion RMB after rounding).

A more interesting case is the related import of crude petroleum and natural gas products (3). Here the contribution of the import coefficient is 30%, indicating a decrease in self-reliance, which, is reinforced by the effects of the increases in demand (+65%) and the positive impact of changes in technology (+11%), leading to a pronounced increase in crude petroleum and natural gas imports with 187 billion RMB. By contrast, eight other sectors show an increase in self-reliance, but the import decline caused by it is quite small, either because the base imports are small (industries 8, 9, 25, and 27) or because the increase in self-reliance is small, as is the case with nonmetal mineral products (13), and common and special products (16).

Changes in technology $\Delta\mathbf{A}$ are the next important type of coefficient change, contributing 8% to the aggregate growth of imports. The sectoral contributions, however, show a large variety of partially compensating positive and negative contributions. Looking at the five industries with the largest import growth, for two of them the contribution of technology changes is positive and larger than the average of 8%. These are telecommunication, computer etc. products (19) with 12% and electric equipment and machinery (18) with 11%, which are sectors that have seen strong changes in technology and/or an increase in vertical specialization.

Besides changes in sectoral technology, domestic final demand preferences $\Delta\mathbf{B}$ also change in the direction of products that are import-intensive. Now, the 5% aggregate contribution hides even larger compensating positive and negative contributions at the sector level. No less than twelve industries show a percentage contribution that is in absolute value larger than 10%. The average change (i.e., either positive or negative) at the sectoral level, may thus be larger than the aggregate effect. Traditional industries (6 and 9) have a large, negative percentage contribution to import growth (but the size of their import growth is relatively small), indicating a shift away from consuming these products. The net positive contribution of preference changes, however, is caused by the shift towards the modern import-intensive products from sectors 16, 19 and 20 (each of which shows a major import growth).

Finally, the change in the composition of export demand $\Delta\mathbf{b}^e$ more or less follows that of domestic final demand; with the shift towards exporting more telecommunication, computer and other electronic equipment (19), which contributes 10% of the absolutely large increase in their imports.

Second, we look at the impact of *macro-economic growth*. As mentioned earlier, the decomposition of China's import growth is conducted in 2000 constant price terms. Still, not surprisingly, macro-economic factors are found to have a larger aggregate impact (65%) than the changes in the model's coefficients (35%). As opposed to the changes in coefficients, however, we hardly see compensating effects in this domain.

The growth of domestic final demand $\Delta\boldsymbol{\sigma}^F$ has the largest contribution to the growth of Chinese imports, with 36% at the aggregate level. Also at the level of individual industries, the growth of domestic final demand often contributes most. This holds especially for the more traditional manufacturing industries (6, 8, 9 and 11), with contributions larger than 65%. The contribution of domestic final demand growth to the imports of more modern products from the industries 19 and 20 (together responsible for two-fifths of the total import growth), of 20% and 23%, however, is smaller than the aggregate contribution of 36%.

Three factors are driving the results for domestic final demand: (i) the growth of the population by 5.8% (71 million people) between 1997 and 2005; (ii) the migration to the major cities, as the per capita urban household consumption is almost four times higher than the per capita rural consumption; (iii) the overall increase in the consumption per capita, which leads to a substantive changes in consumption patterns.[13] These developments mainly explain the relative importance of final demand (both composition and level) for import growth.

Finally, the growth of total exports $\Delta\sigma^e$ accounts for 21% of the aggregate growth of Chinese imports. Its contribution is especially large in the case of the import of textile products (industry 7, 60%), petroleum processing, coking and nuclear fuel processing (11, 47%), and paper, printing and record medium products (10, 41%). It is also relatively important for the growth of imports of (again) telecom etc. products (19, 21%). This latter contribution is clearly of importance, as the

[13] In fact, the shares of agricultural products in rural and urban households consumption bundles have decreased from 38% and 24% in 1997 to 24% and 9% in 2005, respectively. By sharp contrast, the shares of services (industry 32) in their respective consumption bundles have increased from 6% and 10% in 1997 to 12% and 20% in 2005, respectively.

imports of these modern manufacturing products account for 1,201 billion of the total growth of Chinese imports by 3,965 billion RMB.

In summary, changes in coefficients account for 35% of the aggregate increase in imports, but at the level of the individual industries we find a variety of compensating positive and negative impacts. Because these compensating effects take place almost exclusively for coefficient changes, their role is somewhat underestimated. In order to make this visible, we have calculated the *average absolute effect*.[14] They are shown in the bottom row of Table 2.3 (indicated by abs %). Measured in that way, 43% of all the changes (irrespective of the sign) are due to coefficients changes. For macro-economic growth (i.e., the changes in levels) the opposite holds. There the aggregate impact of 65% also hides considerable sectoral variation, but in this case almost all contributions at the industry level have the same positive sign. Therefore, the average absolute effect of the changes in levels is "only" 57%.

2.5 Conclusions and discussion

This chapter contributes methodologically, by presenting a new input-output accounting scheme that offers a separate treatment of processing trade with customer's materials, by presenting an adapted definition of vertical specialization that takes the institutional characteristics of processing trade into account, and by integrating a decomposition of vertical specialization into a decomposition of import growth.

Empirically it shows that the large growth of Chinese vertical specialization, from 21% in 1997 to 30% in 2005, may be attributed for 53% to the growth of import shares, while the remainder may be attributed to changes in the composition of exports and changes in sectoral technology. Surprisingly, vertical specialization and export growth together account for only 38% of the aggregate Chinese import growth. One of the reasons for this outcome is that most of the increase in processing trade is concentrated in one single sector, namely the telecommunication equipment,

[14] That is, if Δ_{ik} indicates the change of imports (in billion RMB) in industry i, due to a change in component k (for example, technology changes $\mathbf{\Delta A}$), the average absolute effect is obtained as $\Sigma_i \left|\Delta_{ik}\right| / \Sigma_i \Sigma_k \left|\Delta_{ik}\right|$.

computer and other electronic equipment industry, whose products account for almost 30% of the total growth in imports.

The outcomes of a more disaggregated decomposition of Chinese import growth into 17 separate components shows that 35% of its aggregate growth may be attributed to changes in the household demand structure, technology and import coefficients, and the remainder to the volume growth of macro-economic demand. Compared with the outcomes of comparable structural decomposition analyses, it appears that the Chinese economy exhibits a remarkably large contribution of structural changes.

This finding is strengthened by the fact that the importance of coefficients changes is somewhat underestimated at the aggregate level. In terms of absolute changes at the industry level, the coefficient changes contribute even 43%. This indicates the tremendous structural changes that occurred in the Chinese economy over this period, which are shown not only in changes in import ratios, but also in changes in sectoral technology and commodity composition of domestic final demand. Underlying these findings, we also expect considerable changes in the spatial economic structure, but to study these two comparable interregional input-output tables would have been required.

In contrast, the contribution of aggregate export change to the aggregate import growth is only 21%. Hence, the idea that Chinese import growth is mainly driven by its export growth is far too simple. Our findings contradict the impression that increasing imports are needed to support the increase in processing exports (see, Koopman et al., 2008; Dean et al., 2008). Structural change and the increase of China's domestic demand for certain products (for example of the industries 6, 7, 8, 9, 25) are more important determinants.

Thus, the empirical results deliver evidence to the debate whether China's growth is sustainable, i.e. whether China is or is not simply continuing along a path of labor-intensive industrialization in which productivity change is subservient to changes in the quantity of factor inputs. It is found that, the sources of import growth in China largely come from structural changes that can be viewed as sustainable.

Appendix

2.A Sector classification in China's input-output tables

Code	Description
1	Agriculture
2	Coal mining, washing and processing
3	Crude petroleum and natural gas products
4	Metal ore mining
5	Non-ferrous mineral mining
6	Manufacture of food products and tobacco processing
7	Textile goods
8	Wearing apparel, leather, furs, down and related products
9	Sawmills and furniture
10	Paper and products, printing and record medium reproduction
11	Petroleum processing, coking and nuclear fuel processing
12	Chemicals
13	Nonmetal mineral products
14	Metals smelting and pressing
15	Metal products
16	Common and special equipment
17	Transport equipment
18	Electric equipment and machinery
19	Telecommunication equipment, computer and other electronic equipment
20	Instruments, meters, cultural and office machinery
21	Other manufacturing products
22	Electricity and heating power production and supply
23	Gas production and supply
24	*Water production and supply*
25	Construction
26	Transport and warehousing
27	Post
28	*Wholesale and retail trade*
29	Accommodation, eating and drinking places
30	Finance and insurance
31	*Real estate*
32	Other services unclassified

2.B Structural decomposition of equation (2-10)

The base decomposition reads as follows: $\Delta\mathbf{m} =$

$$\hat{\mathbf{t}}_{05}\{\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}-\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{97}]^{-1}\}$$
$$\times[(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{B}_{05}\boldsymbol{\sigma}_{05}^{F}+\mathbf{b}_{05}^{e}\sigma_{05}^{e}-\mathbf{b}_{05}^{PCM}\sigma_{05}^{PCM}+\mathbf{b}_{05}^{g}\sigma_{05}^{g}+\boldsymbol{\varepsilon}_{05}] \quad \text{(2-2B.1a)}$$

$$+\{\hat{\mathbf{t}}_{05}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{97}]^{-1}(\mathbf{I}-\hat{\mathbf{t}}_{05})-\hat{\mathbf{t}}_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}(\mathbf{I}-\hat{\mathbf{t}}_{97})\}\mathbf{B}_{05}\boldsymbol{\sigma}_{05}^{F}$$
$$+\{\hat{\mathbf{t}}_{05}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{97}]^{-1}-\hat{\mathbf{t}}_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}\}(\mathbf{b}_{05}^{e}\sigma_{05}^{e}$$
$$-\mathbf{b}_{05}^{PCM}\sigma_{05}^{PCM}+\mathbf{b}_{05}^{g}\sigma_{05}^{g}+\boldsymbol{\varepsilon}_{05})+(\hat{\mathbf{t}}_{05}-\hat{\mathbf{t}}_{97})\mathbf{B}_{05}\boldsymbol{\sigma}_{05}^{F} \quad \text{(2-2B.1b)}$$

$$+\hat{\mathbf{t}}_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}(\mathbf{I}-\hat{\mathbf{t}}_{97})(\mathbf{B}_{05}-\mathbf{B}_{97})\boldsymbol{\sigma}_{05}^{F}+\hat{\mathbf{t}}_{97}(\mathbf{B}_{05}-\mathbf{B}_{97})\boldsymbol{\sigma}_{05}^{F} \quad \text{(2-2B.1c)}$$

$$+\hat{\mathbf{t}}_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{B}_{97}(\boldsymbol{\sigma}_{05}^{F}-\boldsymbol{\sigma}_{97}^{F})+\hat{\mathbf{t}}_{97}\mathbf{B}_{97}(\boldsymbol{\sigma}_{05}^{F}-\boldsymbol{\sigma}_{97}^{F}) \quad \text{(2-2B.1d)}$$

$$+\hat{\mathbf{t}}_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}(\mathbf{b}_{05}^{e}-\mathbf{b}_{97}^{e})\sigma_{05}^{e} \quad \text{(2-2B.1e)}$$

$$-\hat{\mathbf{t}}_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}(\mathbf{b}_{05}^{PCM}-\mathbf{b}_{97}^{PCM})\sigma_{05}^{PCM}+(\mathbf{b}_{05}^{PCM}-\mathbf{b}_{97}^{PCM})\sigma_{05}^{PCM} \quad \text{(2-2B.1f)}$$

$$+\hat{\mathbf{t}}_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}(\mathbf{b}_{05}^{g}-\mathbf{b}_{97}^{g})\sigma_{05}^{g} \quad \text{(2-2B.1g)}$$

$$+\hat{\mathbf{t}}_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}\mathbf{b}_{97}^{e}(\sigma_{05}^{e}-\sigma_{97}^{e}) \quad \text{(2-2B.1h)}$$

$$-\hat{\mathbf{t}}_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}\mathbf{b}_{97}^{PCM}(\sigma_{05}^{PCM}-\sigma_{97}^{PCM})+\mathbf{b}_{97}^{PCM}(\sigma_{05}^{PCM}-\sigma_{97}^{PCM}) \quad \text{(2-2B.1i)}$$

$$+\hat{\mathbf{t}}_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}\mathbf{b}_{97}^{g}(\sigma_{05}^{g}-\sigma_{97}^{g}) \quad \text{(2-2B.1j)}$$

$$+\hat{\mathbf{t}}_{97}\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}(\boldsymbol{\varepsilon}_{05}-\boldsymbol{\varepsilon}_{97}) \quad \text{(2-2B.1k)}$$

The mirror image is given by: $\Delta\mathbf{m} =$

$$\hat{\mathbf{t}}_{97}\{\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{05}]^{-1}-\mathbf{A}_{97}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{97}]^{-1}\}$$
$$\times[(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{B}_{97}\boldsymbol{\sigma}_{97}^{F}+\mathbf{b}_{97}^{e}\sigma_{97}^{e}-\mathbf{b}_{97}^{PCM}\sigma_{97}^{PCM}+\mathbf{b}_{97}^{g}\sigma_{97}^{g}+\boldsymbol{\varepsilon}_{97}] \quad \text{(2-2B.2a)}$$

$$+\{\hat{\mathbf{t}}_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}(\mathbf{I}-\hat{\mathbf{t}}_{05})-\hat{\mathbf{t}}_{97}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{05}]^{-1}(\mathbf{I}-\hat{\mathbf{t}}_{97})\}\mathbf{B}_{97}\boldsymbol{\sigma}_{97}^{F}$$
$$+\{\hat{\mathbf{t}}_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}-\hat{\mathbf{t}}_{97}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{97})\mathbf{A}_{05}]^{-1}\}(\mathbf{b}_{97}^{e}\sigma_{97}^{e}$$
$$-\mathbf{b}_{97}^{PCM}\sigma_{97}^{PCM}+\mathbf{b}_{97}^{g}\sigma_{97}^{g}+\boldsymbol{\varepsilon}_{97})+(\hat{\mathbf{t}}_{05}-\hat{\mathbf{t}}_{97})\mathbf{B}_{97}\boldsymbol{\sigma}_{97}^{F} \quad \text{(2-2B.2b)}$$

$$+\hat{\mathbf{t}}_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}(\mathbf{I}-\hat{\mathbf{t}}_{05})(\mathbf{B}_{05}-\mathbf{B}_{97})\boldsymbol{\sigma}_{97}^{F}+\hat{\mathbf{t}}_{05}(\mathbf{B}_{05}-\mathbf{B}_{97})\boldsymbol{\sigma}_{97}^{F} \quad \text{(2-2B.2c)}$$

$$+\hat{\mathbf{t}}_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{B}_{05}(\boldsymbol{\sigma}_{05}^{F}-\boldsymbol{\sigma}_{97}^{F})+\hat{\mathbf{t}}_{05}\mathbf{B}_{05}(\boldsymbol{\sigma}_{05}^{F}-\boldsymbol{\sigma}_{97}^{F}) \quad \text{(2-2B.2d)}$$

$$+\hat{\mathbf{t}}_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}(\mathbf{b}_{05}^{e}-\mathbf{b}_{97}^{e})\sigma_{97}^{e} \tag{2-2B.2e}$$

$$-\hat{\mathbf{t}}_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}(\mathbf{b}_{05}^{PCM}-\mathbf{b}_{97}^{PCM})\sigma_{97}^{PCM}+(\mathbf{b}_{05}^{PCM}-\mathbf{b}_{97}^{PCM})\sigma_{97}^{PCM} \tag{2-2B.2f}$$

$$+\hat{\mathbf{t}}_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}(\mathbf{b}_{05}^{g}-\mathbf{b}_{97}^{g})\sigma_{97}^{g} \tag{2-2B.2g}$$

$$+\hat{\mathbf{t}}_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}\mathbf{b}_{05}^{e}(\sigma_{05}^{e}-\sigma_{97}^{e}) \tag{2-2B.2h}$$

$$-\hat{\mathbf{t}}_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}\mathbf{b}_{05}^{PCM}(\sigma_{05}^{PCM}-\sigma_{97}^{PCM})+\mathbf{b}_{05}^{PCM}(\sigma_{05}^{PCM}-\sigma_{97}^{PCM}) \tag{2-2B.2i}$$

$$+\hat{\mathbf{t}}_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}\mathbf{b}_{05}^{g}(\sigma_{05}^{g}-\sigma_{97}^{g}) \tag{2-2B.2j}$$

$$+\hat{\mathbf{t}}_{05}\mathbf{A}_{05}[\mathbf{I}-(\mathbf{I}-\hat{\mathbf{t}}_{05})\mathbf{A}_{05}]^{-1}(\boldsymbol{\varepsilon}_{05}-\boldsymbol{\varepsilon}_{97}) \tag{2-2B.2k}$$

The final decomposition consists of the sum of the averages of the corresponding terms:

$\Delta\mathbf{A}$ -effect = [(2-2B.1a) + (2-2B.2a)]/2 $\Delta\mathbf{t}$ -effect = [(2-2B.1b) + (2-2B.2b)]/2

$\Delta\mathbf{B}$ -effect = [(2-2B.1c) + (2-2B.2c)]/2 $\Delta\boldsymbol{\sigma}^{F}$ -effect = [(2-2B.1d) + (2-2B.2d)]/2

$\Delta\mathbf{b}^{e}$ -effect = [(2-2B.1e) + (2-2B.2e)]/2 $\Delta\mathbf{b}^{PCM}$ -effect= [(2-2B.1f) + (2-2B.2f)]/2

$\Delta\mathbf{b}^{g}$ -effect = [(2-2B.1g) + (2-2B.2g)]/2 $\Delta\sigma^{e}$ -effect = [(2-2B.1h) + (2-2B.2h)]/2

$\Delta\sigma^{PCM}$ -effect= [(2-2B.1i) + (2-2B.2i)]/2 $\Delta\sigma^{g}$ -effect = [(2-2B.1j) + (2-2B.2j)]/2

$\Delta\boldsymbol{\varepsilon}$ -effect = [(2-2B.1k) + (2-2B.2k)]/2

CHAPTER 3

HOW MUCH DO EXPORTS CONTRIBUTE TO CHINA'S INCOME GROWTH?[1]

3.1 Introduction

China's rapid economic growth has attracted much attention. The country obviously benefited from its opening-up to the outside world, which started in the late 1970s. Ever since, the growth of trade and gross domestic product (GDP) has soared. Trade grew from less than $21 billion in 1978 to over $3642 billion in 2011. In percentages, the average annual growth rate of China's trade is as high as 17% for the period from 1978 till 2011 (compared with 8% for the world as a whole from 1978 till 2010). Its GDP in constant prices has increased almost 20 times in these three decades.[2] Previous studies (e.g., Feder, 1982; Akyüz, 2011) suggested that this sharp increase of trade triggered China's GDP growth.

In order to estimate the contribution of export growth to GDP growth, a structural decomposition analysis (SDA) based on input-output (IO) tables is considered to be one of the most appropriate methodologies (see Rose and Casler, 1996; and Miller and Blair, 2009, for overviews). SDA has been widely used to account for total output growth (Skolka, 1989; Andreosso-O'Callaghan and Yue, 2002) and for value added changes (Oosterhaven and van der Linden, 1997; Oosterhaven and Hoen, 1998).[3] According to Andreosso-O'Callaghan and Yue, the exports of "*high-tech*" industries, which contain mainly mechanical and electrical products, are amongst the largest contributors to total Chinese output growth between 1987 and 1997. This argument has been widely accepted, not only in academia but also by policy-makers (see e.g.,

[1] This chapter was originally published in *Economic Systems Research*, vol. 24, pp. 275-297, 2012 (jointly written with Jan Oosterhaven and Erik Dietzenbacher).
[2] Table 6-3 in National Bureau of Statistics (2011) gives the "Total value of imports and exports" and Table 2-5 gives the "Indices of Gross Domestic Product" at constant prices, from 1978 till 2010. Trade data for 2011 are from a newly released report by China's General Administration of Customs.
[3] We use GDP and value added interchangeably in this chapter. But a warning is in order: value added can relate to a single industry, whereas GDP only relates to the domestic total.

Jiang, 2002; Guo, 2004; Li et al., 2005).[4] Their result, however, could well be biased becausethey do not distinguish between exports related to processing trade and ordinary exports.[5]

As reported in customs statistics, processing trade began to dominate China's trade in 1996 when it comprised 51% of total trade. In order to take processing trade into account, several studies have estimated the value added embodied in China's foreign exports (Chen et al., 2001; 2009; Lau et al., 2007; Koopman et al., 2008; Dean et al., 2011). By definition, processing exports refer to the assembly of imported materials, which involves a limited input of domestic labor and capital, and results in less domestic value added generation than ordinary exports do. As a consequence, the estimation of the domestic value added content of exports needs a further refinement, as pioneered by Chen et al. (2001; 2009), Lau et al. (2007), Daudin et al. (2008), Koopman et al. (2008), and Johnson and Noguera (2012).

In this chapter we use extended input-output (IO) tables for 2002 and 2007 that explicitly distinguish between production activities related to processing trade and the ordinary production for exports. These extended IO tables partition each production sector into a processing part and the rest. Processing trade has a relatively short production chain in the host country, while ordinary production for exports relies more heavily on backward linkages along the domestic production chain. In other words, these two types of production are expected to have quite different input structures.

Our first important finding is that the contribution of the change in exports to value added changes is 32% larger when the ordinary IO tables are used than when the extended IO tables are used. It is worth noting that this result is in line with other studies on the impact of exports on value added generation (Chen et al., 2001; 2009; Lau et al., 2007; Koopman et al., 2008), on consumption growth (Dietzenbacher et al.,

[4] In fact, the contribution of exports to economic growth is broadly defined. In theory, for instance, consumers may gain from being able to choose from more varieties (Krugman, 1979), or growing exports may facilitate the improvement of aggregate productivity (Melitz, 2003). Frankel and Romer (1999), among others, find empirical support for trade tocause growth. To be clear, in this study we focus only on its contribution to the demand side of the economy.

[5] Different from ordinary trade, with processing trade all or part of the raw and auxiliary materials, parts and components, accessories, and even packaging materials are imported duty-free. After simple processing or assembling activities, the finished products are re-exported. The imported goods registered as processing trade can only be used to produce for the exports; any other use of such imported goods is strictly prohibited.

2007), on carbon dioxide emissions (Dietzenbacher et al., 2009), and on measuring vertical specialization (Yang et al., 2012).

Even more striking are the results at the sectoral level. It is found that the overestimation of the export contribution to value added growth in *Telecommunication equipment, computer and other electronic equipment* is as high as 49%. This result largely contradicts the widely held opinion that exports of "*high-tech*" products contribute substantially to China's tremendous GDP growth (Andreosso-O'Callaghan and Yue, 2002; Jiang, 2002). In fact, our study coincides with research dealing with the issue of whether China's exports are sophisticated. This strand of research demonstrates that so-called "sophisticated exports" like *Telecommunication* contain much foreign value added, which undermines the sophistication argument (see e.g., Schott, 2008; Xu, 2010; Xu and Lu, 2009).

Besides the usual estimation of the contribution of aggregate exports, we also introduce the contribution due to the exports of specific products. Note that conventional SDA calculates the contribution of the different components (e.g., all changes in exports) for the industry where the value added impact is generated. In contrast, this chapter also reports the contribution of product-specific causes (e.g., domestic final demand by product and foreign exports by product) to the total value added growth. Obviously, the latter is a more relevant indicator when discussing industry policy. For "*high-tech*" products from *Telecommunication* (industry 19), the contribution of changes in its exports to total value added growth is overestimated by 63% when the ordinary IO model is used rather than the extended IO model.

To further sharpen the analysis, we refine the SDA methodology in three other dimensions. First, we consider substitution between primary inputs and intermediate inputs. Second, we consider substitution between intermediate inputs (as reported in Dietzenbacher and Los, 2000). Third, we consider substitution of intermediate inputs between a "home" origin and a "foreign" origin (Armington, 1969).

The two most closely related studies are Koopman et al. (2008) and Dean et al. (2011).The estimation of the input-output structure of the processing sector is one of the primary topics of their papers, whereas the present study takes these data from previous research (Lau et al., 2007). Moreover, this chapter performs a structural decomposition analysis. Finally, the present analysis includes the construction of constant price input-output tables, thereby decomposing real value added growth instead of nominal value added growth.

The setup of the chapter is as follows. In Section 3.2 we provide information on the data collection and the model use of ordinary input-output tables. In Section 3.3, the ordinary Leontief model is extended to capture the processing trade. In Section 3.4, the empirical results are given. Section 3.5 concludes and discusses.

3.2 Data processing and ordinary IO modeling

3.2.1 Data issues

The basic data are China's benchmark IO tables for 2002 and 2007 as released by the National Bureau of Statistics (NBS). Figure 3.1 sketches the layout of these tables. **Z** indicates the matrix of intermediate transactions, with z_{ij} denoting the deliveries from (worldwide) industry *i* to China's industry *j*. Analogously, **f** gives the vector with total domestic final demands,[6] with f_i representing the shipments from (worldwide) industry *i* to the Chinese final users. Vector **e** gives Chinese exports by producing industry *i*, and vector **m** gives total Chinese imports (both for intermediate use and for final use) of products from producing industry *i*. Vector **v** contains sectoral gross value added at market prices,[7] and vector **x** contains the total output by industry. A prime indicates the transposition of a vector.

When making inter-temporal comparisons, it is customary to deflate IO tables in order to compare transactions in constant prices. Within the context of SDA, comparing Oosterhaven and Hoen (1998), who use constant prices, with Oosterhaven and van der Linden (1997), who use current prices, yields the following findings. The effects of macro-economic factors, like export growth, are overestimated when current prices are used, whereas those of coefficient changes are underestimated. In the present chapter our main argument is that the presence of processing trade should be taken into account. The emphasis, therefore, lies on comparing growth

[6] The total domestic final demands include rural household consumption, urban household consumption, government expenditures, gross fixed capital formation, and changes in inventories. Although these categories are of interest in themselves, we just present the aggregate results for total domestic final demands as our focus is on the role of exports.

[7] Gross value added includes compensation for employees, depreciation of fixed assets, net taxes on production and operating surplus. In this study we focus on the aggregate impact on value added.

decompositions with non-extended IO tables versus extended IO tables. In addition, the decompositions withcurrent prices and constant prices are compared with one another.

Figure 3.1 Layout of China's benchmark IO table*

<table>
<tr><th rowspan="2"></th><th rowspan="2">Use by industry</th><th colspan="2">Final use</th><th rowspan="2">Import</th><th rowspan="2">Total output</th></tr>
<tr><th>Domestic</th><th>Exports</th></tr>
<tr><td>Intermediate use</td><td>$\mathbf{Z}$</td><td>$\mathbf{f}$</td><td>$\mathbf{e}$</td><td>$-\mathbf{m}$</td><td>$\mathbf{x}$</td></tr>
<tr><td>Value added</td><td>$\mathbf{v}'$</td><td colspan="4" rowspan="2"></td></tr>
<tr><td>Total input</td><td>$\mathbf{x}'$</td></tr>
</table>

*$\mathbf{Z}$ = matrix of intermediate transactions; $\mathbf{f}$ = vector with total domestic final demand; $\mathbf{e}$ = vector with export by producing industry *i*; $\mathbf{m}$ = vector with import (both for intermediate use and for final use) of products from producing industry *i*; $\mathbf{v}$ = vector with total value added; $\mathbf{x}$ = vector with total output.

To arrive at constant prices, the 2007 Chinese IO table is transformed into a table in 2002 prices. In this way, the technical coefficients ($a_{ij} = z_{ij} / x_j$) become "real" technical coefficients that relate to physical units (Miller and Blair, 2009). However, the only price indices available for China relate to gross output per industry. Therefore, the so-called double deflation method is used (Miller and Blair, 2009). This means that for each industry the deflated value added is determined as a residual. Consequently, the estimated real growth in value added will be relatively sensitive to measurement errors. Moreover, it should be noted that domestic products and imported products are assumed to have the same price deflator. Although this is not desirable, it is the only solution since better price index data are not available.

As for details, a price index for the agricultural sector is not available, so that it is proxied by the producer price index (PPI) of agricultural products. The ex-factory price indexes from NBS (2011) for secondary industries are adopted to match the IO sector classification. For IO sectors that do not match exactly with the industries in the Statistical Yearbook, a weighted average is used. Because a price index for construction is not available, we take the price index of fixed capital investments as a substitute. Similarly, the consumer price index (CPI) of different categories is used to proxy the price index for the tertiary industries (all data are from NBS, 2011).

Finally, both the 2002 and 2007 IO tables originally use the same 42-sector classification. Unfortunately, this classification does not entirely match the classification for industry deflators. This problem is overcome by aggregating some of the sectors in the IO tables to a 30-sector classification for which deflators are available (see 3.A).

3.2.2 Ordinary input-output modeling

The essence of building an input-output model is adding behavioral assumptions and equations to the accounting identities of an IO table. First, we specify the IO model that would correspond to the official Chinese IO table. In Figure 4.1, we have $\mathbf{x} = \mathbf{Zi} + \mathbf{f} + \mathbf{e} - \mathbf{m}$ as accounting identities along the rows of the IO table, where $\mathbf{i}$ indicates a summation vector consisting of ones. This IO model first assumes that the supply of output $\mathbf{x}$ follows total *net* demand $\mathbf{Zi} + \mathbf{f} + \mathbf{e} - \mathbf{m}$. Next, it assumes that endogenous intermediate demand for worldwide products is determined by total output, i.e. $\mathbf{Zi} = \mathbf{Ax}$, in which the technical coefficients matrix is calculated by $\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$ (a hat indicates a diagonal matrix). Consequently, the solution of this IO model equals $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}(\mathbf{f} + \mathbf{e} - \mathbf{m})$.[8]

A major problem of the official Chinese IO tables is that they do not distinguish between domestically produced inputs and imported inputs. As suggested by Oosterhaven and van der Linden (1997), the necessary matrix with domestic input coefficients can be estimated as the product of technical coefficients and domestic trade coefficients, i.e. self-sufficiency ratios. Define $\mathbf{t}$ as the vector with foreign import coefficients that are calculated as $t_i = m_i / (x_i - e_i + m_i)$. Then, using the so-called proportional method (see, e.g., Lahr, 2001; Pei et al., 2011a), the domestically produced intermediate inputs can be estimated as $\mathbf{Z}^D\mathbf{i} = (\mathbf{I} - \hat{\mathbf{t}})\mathbf{Ax} = \hat{\mathbf{t}}^D\mathbf{Ax}$, with $\mathbf{I}$ the identity matrix and $\hat{\mathbf{t}}^D$ a diagonal matrix with self-sufficiency ratios. The same method is used to estimate the domestically produced final demand, as $\mathbf{f}^D = \hat{\mathbf{t}}^D\mathbf{f}$.

[8] This model, however, is not very plausible for two reasons. First, it assumes that the endogenous intermediate inputs from the rest of the world are produced by Chinese industries. Second, it assumes that total imports are exogenous, i.e. they do not depend on the size of domestic intermediate and final demand, which may lead to inconsistency with the endogenous intermediate imports.

The accounting identity $\mathbf{x} = \mathbf{Zi} + \mathbf{f} + \mathbf{e} - \mathbf{m}$ can now be rewritten so as to cover the deliveries of domestically produced goods only. Thus, foreign imports $\mathbf{m}$ are excluded in the rewritten accounting identity $\mathbf{x} = \mathbf{Z}^D\mathbf{i} + \mathbf{f}^D + \mathbf{e}$. Next, the two behavioral equations introduced above are substituted into this new accounting identity, which leads to the following data-specific solution of the "ordinary" IO model

$$\mathbf{x} = (\mathbf{I} - \hat{\mathbf{t}}^D\mathbf{A})^{-1}(\hat{\mathbf{t}}^D\mathbf{f} + \mathbf{e}) = \mathbf{L}(\mathbf{f}^D + \mathbf{e}) \tag{3-1}$$

where $\mathbf{L}$ denotes the Leontief inverse $\mathbf{L} = (\mathbf{I} - \hat{\mathbf{t}}^D\mathbf{A})^{-1}$. Note that the substitution between "domestic" and "foreign" within all IO cells is dealt with explicitly.

However, as pointed out in the literature (see for instance, Oosterhaven and van der Linden, 1997), value added is more relevant in terms of policy analysis than total output.[9] Hence, we introduce a third behavioral equation that explains industry value added from industry total output, with $\mathbf{v} = \hat{\mathbf{c}}\mathbf{x}$, where $\mathbf{v}$ is a vector with value added by industry and $\hat{\mathbf{c}}$ is a diagonal matrix with value added coefficients, calculated as $c_i = v_i / x_i$. Then the data-specific solution of the "ordinary" IO model for $\mathbf{v}$ reads as follows:

$$\mathbf{v} = \hat{\mathbf{c}}(\mathbf{I} - \hat{\mathbf{t}}^D\mathbf{A})^{-1}(\hat{\mathbf{t}}^D\mathbf{f} + \mathbf{e}) \tag{3-2}$$

Note that the changes in the value added coefficients $\mathbf{c}$ are dependent on the changes in the technical coefficients $\mathbf{A}$, as $\mathbf{c}' + \mathbf{i}'\mathbf{A} = \mathbf{i}'$ (see Dietzenbacher and Los, 2000, for the general problem of dependence between components in a SDA).

Here, we solve the problem of the dependency between components by explicitly separating the substitution between total primary inputs (capital, labor, and land) and total intermediate inputs (i.e., the changes in $\mathbf{c}$), from the substitution ofintermediate inputs among each other (i.e., the changes in the *normalized* technical coefficients

[9] This proposition receives more and more recognition. On June 6, 2011, for instance, WTO Director-General Pascal Lamy suggests "trade in value-added" as a better measurement of world trade. He pointed out that "…traditional trade statistics give us a distorted picture … [It] would be different if we took account of how much domestic value-added is embedded in these flows [.]" (Source: http://www.wto.org/english/news_e/news11_e/miwi_06jun11_e.htm)

$\mathbf{A}^n$), where $\mathbf{A}^n = \mathbf{A}(\mathbf{I}-\hat{\mathbf{c}})^{-1}$, with $(\mathbf{I}-\hat{\mathbf{c}}) = \text{diag}(\mathbf{i}'\mathbf{A})$. Obviously, $\mathbf{i}'\mathbf{A}^n = \mathbf{i}'$. Then, formula (3-2) can be extended as

$$\mathbf{v} = \hat{\mathbf{c}}(\mathbf{I}-\hat{\mathbf{t}}^D\mathbf{A}^n(\mathbf{I}-\hat{\mathbf{c}}))^{-1}(\hat{\mathbf{t}}^D\mathbf{f}+\mathbf{e}) \tag{3-3}$$

As regards the decomposition of final demand, define $\mathbf{b}^f$ as a vector with the industry shares in final demand (indicating preferences and taste) and φ^f as a scalar with the level of total final demand, then we have $\mathbf{f} = \varphi^f\mathbf{b}^f$. Similarly, define $\mathbf{b}^e$ as a vector with industry shares in foreign exports and φ^e as a scalar with the total level of foreign exports, which gives $\mathbf{e} = \varphi^e\mathbf{b}^e$. Then, formula (3-3) can further be extended as:

$$\mathbf{v} = \hat{\mathbf{c}}(\mathbf{I}-\hat{\mathbf{t}}^D\mathbf{A}^n(\mathbf{I}-\hat{\mathbf{c}}))^{-1}(\hat{\mathbf{t}}^D\mathbf{b}^f\varphi^f+\mathbf{b}^e\varphi^e) \tag{3-4a}$$

This is our basic formula for the SDA of Chinese value added growth. It shows how value added *by industry* depends on five sets of coefficients and two levels of final demand, i.e. domestic final demands and foreign exports.

Equation (3-2) can be considered in more details by linking the industry value added to final demand *by product* with $\mathbf{V} = \hat{\mathbf{c}}(\mathbf{I}-\hat{\mathbf{t}}^D\mathbf{A}^n(\mathbf{I}-\hat{\mathbf{c}}))^{-1}(\hat{\mathbf{t}}^D\hat{\mathbf{b}}^f\varphi^f+\hat{\mathbf{b}}^e\varphi^e)$. Its typical element v_{ij} gives the value added in industry *i* due to the final demands (domestic and exports) for product *j*. The basic equation (3-4a) takes the row sums of the matrix **V**. Alternatively, we may also take the column sums, which yields

$$\bar{\mathbf{v}}' = \mathbf{c}'(\mathbf{I}-\hat{\mathbf{t}}^D\mathbf{A}^n(\mathbf{I}-\hat{\mathbf{c}}))^{-1}(\hat{\mathbf{t}}^D\hat{\mathbf{b}}^f\varphi^f+\hat{\mathbf{b}}^e\varphi^e) \tag{3-4b}$$

Equation (3-4b) shows how the *aggregate* value added that is due to the final demand for one specific product, depends on the same seven components. It gives the value added as embodied in the final demand by product. Contrary to (3-4a), it does not specify the industry-specific consequences. Instead, it specifies the two most important industry-specific causes of that change, as the diagonal matrices in (3-4b) allow for the calculation of the impact of the separate elements of domestic final demands and foreign exports.

3.3 Extending the ordinary model with processing trade

As shown in Lau et al. (2007), Koopman et al. (2008), and Johnson and Noguera (2012), the presence of processing trade changes the conventional perception of the impact of trade. To capture this phenomenon, the production of processing trade products should be separated from the production of ordinary products. Extended IO tables that correspond to the ordinary national IO tables but distinguish firms producing for "domestic use and non-processing trade" from firms producing for "processing trade" have been constructed by the research team of Xikang Chen in co-operation with the NBS (see Chen et al., 2001; 2009).[10]

Figure 3.2 The extended IO table with processing trade

		Use by industry		Final use		Total
		Other	*Processing*	*Domestic*	*Exports*	
Intermediate use	*Other**	$\mathbf{Z}^{OO}$	$\mathbf{Z}^{OP}$	$\mathbf{f}^{O}$	$\mathbf{e}^{O}$	$\mathbf{x}^{O}$
	Processing	$\mathbf{0}$	$\mathbf{0}$	$\mathbf{0}$	$\mathbf{e}^{P}$	$\mathbf{e}^{P}$
	Imported	$\mathbf{Z}^{MO}$	$\mathbf{Z}^{MP}$	$\mathbf{f}^{M}$	$\mathbf{0}$	$\mathbf{m}$
Value added		$(\mathbf{v}^{O})'$	$(\mathbf{v}^{P})'$			
Total input		$(\mathbf{x}^{O})'$	$(\mathbf{x}^{P})'$			

* *Other* = industries *other* than producing processing exports; *Processing* = those producing processing exports. The same note as Figure 3.1; superscripts indicate flows from type *O* to type *P*, and/or flows imported by type *O* and type *P*.

In fact, their extended IO tables distinguish three types of production firms: processing exports; domestic use only; and non-processing exports and other production by foreign-invested enterprises. In order to assess the impact of processing trade on income changes, their 2002 and 2007 extended IO tables are aggregated to

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[10] As familiar from the heterogeneous firms' literature (cf. Melitz, 2003), it is crucial to distinguish firms producing processing exports from other firms, as they are different in productivity, production structure and so forth. We would like to acknowledge NBS China and Professor Chen and his research team for providing the raw data that made this study possible.

include only two types of production, i.e. producing processing exports and other production. Figure 3.2 sketches the layout of the aggregated version of the extended IO table that is used for the SDA.

We are now able to extend the standard IO model to incorporate processing trade within one consistent framework. Observe that the IO accounting framework in Figure 3.2 has a structure that closely resembles that of an interregional IO table, where superscripts *RS* indicate shipments from region *R* to region *S*. Instead of regions, the extended framework has two types of production by the same 30 industries, namely production for processing exports (*P* type) and other production (*O* type). According to Chinese regulations, the goods termed *processing trade* can only be exported, which means that domestic sales are absent. So, we have zeros in the corresponding submatrices.[11] Simply aggregating $\mathbf{Z}^{OO}$, $\mathbf{Z}^{MO}$, $\mathbf{Z}^{OP}$ and $\mathbf{Z}^{MP}$ gives the $\mathbf{Z}$ matrix of the ordinary IO table in Figure 3.1. In the same fashion, the domestic final demands, exports, values added, imports and total outputs of Figure 3.1 can be obtained from Figure 3.2.

From the extended IO table of Figure 3.2, the corresponding extended IO model is derived in the usual fashion. First, define $\mathbf{A}^{OO} = \mathbf{Z}^{OO}(\hat{\mathbf{x}}^{O})^{-1}$ and $\mathbf{A}^{OP} = \mathbf{Z}^{OP}(\hat{\mathbf{x}}^{P})^{-1}$ as the domestic input coefficients of the *O* type industries and the *P* type industries, respectively. Then, the extended Leontief-inverse reads as follows:

$$\tilde{\mathbf{L}} = (\mathbf{I} - \tilde{\mathbf{A}}^{D})^{-1} = \begin{bmatrix} \mathbf{I} - \mathbf{A}^{OO} & -\mathbf{A}^{OP} \\ \mathbf{0} & \mathbf{I} \end{bmatrix}^{-1} = \begin{bmatrix} \mathbf{L}^{OO} & \mathbf{L}^{OO}\mathbf{A}^{OP} \\ \mathbf{0} & \mathbf{I} \end{bmatrix} \tag{3-5}$$

When (3-5) is substituted in the extended equation for value added, its solution reads as:

$$\begin{bmatrix} \mathbf{v}^{O} \\ \mathbf{v}^{P} \end{bmatrix} = \begin{bmatrix} \hat{\mathbf{c}}^{O} & 0 \\ 0 & \hat{\mathbf{c}}^{P} \end{bmatrix} \begin{bmatrix} \mathbf{L}^{OO} & \mathbf{L}^{OO}\mathbf{A}^{OP} \\ 0 & \mathbf{I} \end{bmatrix} \begin{bmatrix} \mathbf{f}^{O} + \mathbf{e}^{O} \\ \mathbf{e}^{P} \end{bmatrix}$$

This gives the following *aggregate* solution for value added by industry

[11] A full exposition of the development of the extended IO tables is beyond the scope of this study. For further details see Chen et al. (2001; 2009) and Lau et al. (2007).

$$\mathbf{v} = \mathbf{v}^O + \mathbf{v}^P = \hat{\mathbf{c}}^O \mathbf{L}^{OO} (\mathbf{f}^O + \mathbf{e}^O) + \hat{\mathbf{c}}^O \mathbf{L}^{OO} \mathbf{A}^{OP} \mathbf{e}^P + \hat{\mathbf{c}}^P \mathbf{e}^P \quad (3\text{-}6)$$

We use the same further division of coefficients as in (3-4). To this end, we introduce $\mathbf{\Omega}$ to indicate how the technical coefficients of the processing trade sector *P* and the other production sector *O* deviate from the average technical coefficients (which may be interpreted as a country's production possibility frontier). That is, we introduce $\mathbf{\Omega}^O$ with $\omega_{ij}^O = a_{ij}^O / a_{ij}$, and $\mathbf{\Omega}^P$ with $\omega_{ij}^P = a_{ij}^P / a_{ij}$, representing the relative difference of *O* and *P* type technologies to the benchmark technology. Thus, $\mathbf{A}^O = \mathbf{\Omega}^O \otimes \mathbf{A}$ and $\mathbf{A}^P = \mathbf{\Omega}^P \otimes \mathbf{A}$, where the Hadamard product $\otimes$ indicates a cell-by-cell multiplication. In the same fashion, $\mathbf{s}^O$ is introduced to indicate the deviation of the *O* type value added coefficients from the average value added coefficients, with $s_i^O = c_i^O / c_i$ and $c_i^O = v_i^O / x_i^O$; while $\mathbf{s}^P$ is defined in the same way. Thus, $\hat{\mathbf{c}}^O = \hat{\mathbf{s}}^O \hat{\mathbf{c}}$ and $\hat{\mathbf{c}}^P = \hat{\mathbf{s}}^P \hat{\mathbf{c}}$.

Analogous to the derivation of the domestic input coefficients in the ordinary IO model, we define $\mathbf{A}^{OO}$ by the products of the self-sufficiency ratios of intermediate inputs ($t_{ij}^O = a_{ij}^{OO} / a_{ij}^O$) and the technical coefficients of *O* type production ($a_{ij}^O = (z_{ij}^{OO} + z_{ij}^{MO}) / x_j^O$). In the same fashion, $\mathbf{A}^{OP}$ is defined by the products of $t_{ij}^P = a_{ij}^{OP} / a_{ij}^P$ and $a_{ij}^P = (z_{ij}^{OP} + z_{ij}^{MP}) / x_j^P$.

Thus, $\mathbf{A}^{OO} = \mathbf{T}^O \otimes \mathbf{A}^O$ and $\mathbf{A}^{OP} = \mathbf{T}^P \otimes \mathbf{A}^P$. Again using $\mathbf{A} = \mathbf{A}^n (\mathbf{I} - \hat{\mathbf{c}})$, we have $\mathbf{L}^{OO} = [\mathbf{I} - \mathbf{T}^O \otimes \mathbf{\Omega}^O \otimes \mathbf{A}^n (\mathbf{I} - \hat{\mathbf{c}})]^{-1}$. Again, analogous to the derivation of domestic final demands in the ordinary IO model, self-sufficiency ratios for final demands $t_i^f = f_i^O / (f_i^O + f_i^M)$ are multiplied with sectoral final demand shares $b_i^f = (f_i^O + f_i^M) / \varphi^f$ and the level of total domestic final demand $\varphi^f = \mathbf{i}'\mathbf{f}$. This yields $\mathbf{f}^O = \hat{\mathbf{t}}^f \mathbf{b}^f \varphi^f$. Note that, contrary to the ordinary IO model, the extended IO framework allows us to distinguish between the self-sufficiency ratios of final demand and those of intermediate demand of *O* products and even of *P* products.

Finally, in order to distinguish the exports of *O* products from those of *P* products, $\boldsymbol{\tau}^O$ is defined as the vector with the shares of *O* products in total export by industry, i.e. $\tau_i^O = e_i^O / e_i$. Then, $1-\tau_i^O = e_i^P / e_i$ defines the share of P products, as $e_i = e_i^O + e_i^P$. This yields $\mathbf{e}^O = \hat{\boldsymbol{\tau}}^O \mathbf{b}^e \varphi^e$ and $\mathbf{e}^P = (\mathbf{I}-\hat{\boldsymbol{\tau}}^O)\mathbf{b}^e \varphi^e$.

With these additional definitions, equation (3-6) can be rewritten to obtain the equivalent of expression (3-4a) for the extended model.

$$\mathbf{v} = \hat{\mathbf{s}}^O \hat{\mathbf{c}}[\mathbf{I}-\mathbf{T}^O \otimes \boldsymbol{\Omega}^O \otimes \mathbf{A}^n(\mathbf{I}-\hat{\mathbf{c}})]^{-1}(\hat{\mathbf{t}}^f \mathbf{b}^f \varphi^f + \hat{\boldsymbol{\tau}}^O \mathbf{b}^e \varphi^e) \tag{3-7.1a}$$

$$+\hat{\mathbf{s}}^O \hat{\mathbf{c}}[\mathbf{I}-\mathbf{T}^O \otimes \boldsymbol{\Omega}^O \otimes \mathbf{A}^n(\mathbf{I}-\hat{\mathbf{c}})]^{-1}[\mathbf{T}^P \otimes \boldsymbol{\Omega}^P \otimes \mathbf{A}^n(\mathbf{I}-\hat{\mathbf{c}})][(\mathbf{I}-\hat{\boldsymbol{\tau}}^O)\mathbf{b}^e \varphi^e] \tag{3-7.2a}$$

$$+\hat{\mathbf{s}}^P \hat{\mathbf{c}}[(\mathbf{I}-\hat{\boldsymbol{\tau}}^O)\mathbf{b}^e \varphi^e] \tag{3-7.3a}$$

Equation (3-7.1a) gives the value added by industry of *Other production* due to domestic final demand and non-processing exports; equation (3-7.2a) shows the value added of *Other production* due to processing exports; while equation (3-7.3a) represents value added of production for *Processing trade* due to processing exports. In (3-7a) we have 14 components that contribute to value added changes. Formulas (3-7a) reduce to the ordinary IO model of (3-4a) if zeros are assigned to coefficients (or values) that relate to P type industries.

As in the case of (3-4a), formulas (3-7a) are used to measure the impacts on the value added growth in each individual industry. To investigate the value added as embodied in the final demand for individual products, i.e. as was done in the case of (3-4b), the following equivalent expression is used for the extended model.

$$\bar{\mathbf{v}}' = \mathbf{c}'\hat{\mathbf{s}}^O[\mathbf{I}-\mathbf{T}^O \otimes \boldsymbol{\Omega}^O \otimes \mathbf{A}^n(\mathbf{I}-\hat{\mathbf{c}})]^{-1}(\hat{\mathbf{t}}^f \hat{\mathbf{b}}^f \varphi^f + \hat{\boldsymbol{\tau}}^O \hat{\mathbf{b}}^e \varphi^e) \tag{3-7.1b}$$

$$+\mathbf{c}'\hat{\mathbf{s}}^O[\mathbf{I}-\mathbf{T}^O \otimes \boldsymbol{\Omega}^O \otimes \mathbf{A}^n(\mathbf{I}-\hat{\mathbf{c}})]^{-1}[\mathbf{T}^P \otimes \boldsymbol{\Omega}^P \otimes \mathbf{A}^n(\mathbf{I}-\hat{\mathbf{c}})][(\mathbf{I}-\hat{\boldsymbol{\tau}}^O)\hat{\mathbf{b}}^e \varphi^e] \tag{3-7.2b}$$

$$+\mathbf{c}'\hat{\mathbf{s}}^P[(\mathbf{I}-\hat{\boldsymbol{\tau}}^O)\hat{\mathbf{b}}^e \varphi^e] \tag{3-7.3b}$$

Finally, to decompose the 2002-2007 value added growth as explained by (3-4a)-(3-4b) and (3-7a)-(3-7b) into the changes of their 7 and 14 components, respectively, we take the average of two so-called polar decompositions. The principle of polar decompositions is to alternate the dated coefficients and variables that determine the size of the impact of a specific change in such a way that both years, e.g. 0 and 1, only occur once. This principle can best be shown by means of the simplest SDA with only two components.

Suppose $\mathbf{R} = \mathbf{S}\mathbf{T}$, then the change in **R** can be ascribed to the changes in **S** and **T** as follows (**S** and **T** are independent from each other).

$$\Delta\mathbf{R} = \mathbf{S}_1\mathbf{T}_1 - \mathbf{S}_0\mathbf{T}_0$$

$$= \mathbf{S}_1\mathbf{T}_1 - \mathbf{S}_0\mathbf{T}_1 + \mathbf{S}_0\mathbf{T}_1 - \mathbf{S}_0\mathbf{T}_0 = \Delta\mathbf{S}\,\mathbf{T}_1 + \mathbf{S}_0\,\Delta\mathbf{T} \qquad (\textit{one polar}) \qquad (3\text{-}8.1)$$

$$= \mathbf{S}_1\mathbf{T}_1 - \mathbf{S}_1\mathbf{T}_0 + \mathbf{S}_1\mathbf{T}_0 - \mathbf{S}_0\mathbf{T}_0 = \mathbf{S}_1\,\Delta\mathbf{T} + \Delta\mathbf{S}\,\mathbf{T}_0 \qquad (\textit{counter-polar}) \qquad (3\text{-}8.2)$$

$$= 0.5\,(\mathbf{S}_0 + \mathbf{S}_1)\,\Delta\mathbf{T} + 0.5\,\Delta\mathbf{S}\,(\mathbf{T}_0 + \mathbf{T}_1) \qquad (\textit{the average}) \qquad (3\text{-}8.3)$$

Equations (3-8.1) and (3-8.2) are equivalent from a mathematical point of view; the only difference is that they use alternating weights. From an economic viewpoint the different decompositions are clearly related to the so-called *Laspeyres*, *Paasche* and *Fisher* indexes, and point at the index number problem, which is solved in SDA by taking the average of two polar decompositions.[12] Dietzenbacher and Los (1998) show that this average produces a good approximation of the average of all possible 7! decompositions of (3-4a)-(3-4b), and all possible 14! decompositions of (3-7a)-(3-7b). Hence, the actual polar decompositions of (3-4a)-(3-4b) and (3-7a)-(3-7b) are derived in the same fashion as in (3-8).[13]

3.4 Empirical results by using the extended IO framework

The empirical results of these decompositions are discussed in four parts. To set the stage, first, the importance of processing exports and imports is discussed, both over time and across industries. Second, we quantify the aggregate bias that occurs in estimating the contribution of export growth to GDP growth, when processing trade is not distinguished. Third, we discuss the decomposition results due to product-specific causes, using the alternative formulas (3-4b) and (3-7b). Fourth, the impacts on industry-specific values added are examined, using equations (3-4a) and (3-7a). All

[12] See Skolka (1989), Oosterhaven and van der Linden (1997), or Dietzenbacher et al. (2004) for a detailed discussion.

[13] The very lengthy SDA expressions for (3-4a)-(3-4b) and (3-7a)-(3-7b) are essentially extensions of (3-8.1)-(3-8.3). In order to save space, their derivation and formulation are omitted here, but are available upon request.

calculations are done with both constant and current prices, but the focus is on the decomposition of the real growth in value added.

3.4.1 The importance of Chinese processing trade

Before we discuss the contribution of export growth to Chinese GDP growth, Table 3.1 shows some statistics on the composition of exports and imports, and the shares of processing trade therein. The exports of industry 1 (agriculture), for example, amount to 1.5 per cent of the total exports in 2002, while 2.7 per cent of the agricultural exports are processing exports.

It is clear that processing trade takes a very important position in China's foreign trade. In 2002 the average share of processing exports is 48%, and in six out of 30 industries more than half of their exports are processing exports. Observe that the three industries producing mechanical and electrical products (i.e., industries 18-20) are responsible for 28% of the total exports in 2002. These "*high-tech*" industries are also heavily involved in processing exports. No less than 23% of the total exports are processing exports from these "*high-tech*" industries 18-20. The role of industry 19 (*telecommunication* etc.) stands out, in particular. At the same time, however, the "*low-tech*" industries 7 (*textile goods*) and 8 (*wearing apparel* etc.) also have a substantial share in total exports (18%), and have a relatively large component of processing exports (together 7.0 per cent of total exports).

A similar structure can be found for 2007, although small shifts are observed. For instance, the overall role for processing exports has reduced a little to 46%. The three "*high-tech*" industries 18-20, however, saw increases in both their already large share in total exports to 35%, while their processing exports' share in total exports rose to 28%. This is caused by the changes for industry 19, in particular. The share of its exports rose by 7.5 percentage points, while the share of processing exportsin the total exports of industry 19 rose with 2.5 percentage points. An opposite shift took place for the "*low-tech*" industries 7 and 8. Their share in total exports fell to 14%, while both industries experienced decliningshares of processing exports (so that the share of their processing exports in total exports decreased to as little as 3.0 per cent).

Table 3.1 Industry export shares and shares of processing trade exports per industry (%)*

Industry	2002 export	Proc.tr. share	2007 export	Proc.tr. share	2002 import	Proc.tr. share	2007 import	Proc.tr. share
1	1.5	2.7	0.7	0.0	2.5	36.7	2.9	14.3
2	0.5	0.5	0.2	0.0	0.1	0.8	0.2	0.0
3	0.4	0.5	0.2	0.0	4.1	3.9	7.6	6.6
4	0.1	7.6	0.1	18.0	1.4	7.7	5.1	1.4
5	0.5	30.6	0.2	56.6	0.7	13.4	0.6	34.6
6	2.9	26.4	2.0	26.9	2.0	23.8	2.0	15.1
7	8.8	28.9	8.3	17.3	4.5	62.8	1.6	80.0
8	9.0	46.4	6.1	32.1	1.6	28.5	0.9	56.8
9	2.2	41.5	2.4	27.6	0.7	53.8	0.4	33.1
10	3.2	71.8	2.6	60.2	2.0	49.6	1.2	34.8
11	0.8	23.3	0.9	37.8	1.5	38.9	1.8	5.5
12	7.0	40.1	7.4	36.7	13.0	43.9	12.0	33.9
13	1.4	18.1	1.5	13.4	0.7	72.6	0.5	53.3
14	1.5	38.0	5.2	11.4	5.9	61.7	5.8	43.7
15	3.4	46.1	3.6	32.5	2.0	72.3	0.8	41.1
16	4.2	38.2	5.7	33.1	11.6	12.0	8.8	13.6
17	2.1	49.7	3.2	42.0	3.7	22.8	3.7	3.5
18	6.6	66.2	7.2	58.7	6.2	45.7	4.7	52.4
19	16.1	85.8	23.6	88.3	20.7	60.5	22.8	65.2
20	4.8	91.1	3.9	81.5	6.0	10.9	6.8	50.4
21	1.4	54.8	1.5	34.3	0.4	49.1	2.3	17.0
22	0.0	100.0	0.1	41.1	0.9	0.0	0.0	0.0
23	0.2	2.4	0.0	0.0	0.0	15.5	0.0	0.0
24	0.0	0.5	0.0	0.0	0.5	0.0	0.0	0.0
25	0.3	0.5	0.4	0.0	0.3	0.0	0.3	0.0
26	4.7	17.0	4.0	6.4	1.1	0.0	1.4	6.2
27	1.1	2.3	0.4	15.8	0.4	14.8	1.2	5.0
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	1.1	36.6	0.7	0.0	0.0	0.0	0.6	1.4
30	14.3	32.8	7.9	25.2	5.5	0.0	4.0	0.9
Total	100%	48.1	100%	45.7	100%	36.8	100%	33.8

* Authors' computation based on the extended IO tables for 2002 and 2007, constructed by the NBS China and Prof. Xikang Chen's research team. Pro.tr. share = processing trade as a portion of total trade.

Turning to the import side, we see a downward trend in the average share of processing imports from 37% in 2002 to 34% in 2007. It is worth stressing that these imports are by industry of origin, i.e. by type of product. At industry level, we see that the "*high-tech*" products (and in particular those in *telecommunication* etc.) are also important on the import side. Increases are observed for both their share in total imports and the role of processing imports in that share. As a consequence, processing imports as a share of total imports increased from 16% to 21%. Another major import product is *chemicals* (industry 12). Its import share fell somewhat and so did its share of processing imports therein, although they both remained substantial. In 2007, the processing imports of the "*low-tech*" products from industries 7 and 8 increasedin terms of shares (with, respectively, 17% and 28%); yet their importance in the overall basket of import products has declined dramatically (respectively, from 4.5 per cent to 1.6 per cent and from 1.6 percent to 0.9 per cent).

It is clear that the "*high-tech*" industries have grown in importance as far as processing trade is concerned. Both their trade shares and the processing shares therein have increased for imports as well as for exports (see e.g., industry 19 in Table 3.1). This goes against the conventional ideas on developments over time. That is, at an early point in time many imports aredoneby foreign-invested enterprises for their processing trade activities. Due to "learning-by-doing" and "catching-up", however, domestic firms become involved in the foreign trade in these products as well (see Jiang, 2002), and, consequently, engage in ordinary export activities themselves. This may change the composition of both processing imports and ordinary imports. Clearly, this is not what we observe in Table 3.1.

The continued importance of processing trade provides a strong indication that studies that fail to take account of processing trade, may come up with biased estimates or misleading conclusions. This may be the case with Andreosso-O'Callaghan and Yue (2002) who analyze China's output growth,[14] with Guan et al. (2009) who account for the changes in China's emissions, and with Weber et al. (2008) who estimate the exports' contribution to China's CO_2 emissions. Here we deal explicitly with processing trade in order to better account for the impact of trade on China's GDP growth.

3.4.2 The aggregate estimation error when processing trade is disregarded

To provide a brief overview of our findings, we first present the aggregate results in Table 3.2. Recall that we have refined the methodology in three aspects, thus taking

[14] The estimation given in Lau et al. (2007) may serve as a benchmark. They report, for example, that for *Telecommunication equipment, computer and other electronic equipment* (industry 19) 100 RMB of processing exports generate 20 RMB value added, whereas non-processing exports generate 42 RMB value added in 2002.

into account the substitution (i) between primary inputs and intermediate inputs; (ii) between intermediate inputs among each other; and (iii) between “home” and “foreign” within each cell of the IO table. This led to equation (3-7a) for the value added generated in industries and to equation (3-7b) for the value added embodied in “final” products. The aggregate results are obtained by summing the detailed results and are, of course, the same for both (3-7a) and (3-7b). In order to make a comparison, we also run the calculations with the ordinary IO tables, with (3-4a) or (3-4b).

Table 3.2 Decomposition of China’s value added growth in constant prices for 2002-2007*

	Total	$\Delta\mathbf{c}$	$\Delta\mathbf{A}^n$	$\Delta\mathbf{t}^D$	$\Delta\mathbf{b}^f$	$\Delta\mathbf{b}^e$	$\Delta\varphi^f$	$\Delta\varphi^e$
With the ordinary IOM	12,350	-1.4	-2.9	-0.1	-2.3	-2.1	66.0	42.8
		$\Delta\mathbf{c}$	$\Delta\mathbf{A}^n$	$\Delta\mathbf{T}^O$	$\Delta\mathbf{b}^f$	$\Delta\mathbf{b}^e$	$\Delta\varphi^f$	$\Delta\varphi^e$
With the extended IOM	12,350	-1.0	-3.4	-0.7	-2.3	-3.8	70.0	34.6
		$\Delta\mathbf{T}^P$	$\Delta\mathbf{\Omega}^P$	$\Delta\mathbf{\Omega}^O$	$\Delta\mathbf{s}^O$	$\Delta\mathbf{s}^P$	$\Delta\boldsymbol{\tau}^O$	$\Delta\mathbf{t}^f$
		-0.7	3.4	2.3	-1.6	1.9	1.5	-0.2

* Total change is in billion RMB, in 2002 constant prices; components’ contributions are in % that add to 100%.

Note: IOM, Input-Output model. $\Delta\mathbf{c}$ = changes in value added coefficients; $\Delta\mathbf{A}^n$ = changes in *normalized* technical coefficients; $\Delta\mathbf{t}^D$ = changes in trade coefficients; $\Delta\mathbf{b}^f$ = changes in bridge coefficients; $\Delta\mathbf{b}^e$ = changes in export composition; $\Delta\varphi^f$ = change in level of final use; $\Delta\varphi^e$ = change in total export; $\Delta\mathbf{T}^O$ and $\Delta\mathbf{T}^P$ = changes in self-sufficiency coefficients of *O* and *P* type; $\Delta\mathbf{\Omega}^O$ and $\Delta\mathbf{\Omega}^P$ = changes in relative differences of *O* and *P* type technologies to the benchmark technology; $\Delta\mathbf{s}^O$ and $\Delta\mathbf{s}^P$ = changes in relative differences of *O* and *P* type value added coefficients from the average value added coefficients; $\Delta\boldsymbol{\tau}^O$ = changes in shares of *O* products in total export by industry; $\Delta\mathbf{t}^f$ = changes in self-sufficiency coefficients for final demands.

Value added in China has increased by 12,350 billion RMB (in 2002 constant prices, see Table 3.2). In the upper panel, if only the level of the exports ($\Delta\varphi^e$) had changed as it actually did, while (*ceteris paribus*) everything else remained the same, value added would have increased by 43% of the actual increase (i.e., by 5,286 billion RMB), if the ordinary IO table is used. If the extended model is used (see the lower panel), the change in the exports level ($\Delta\varphi^e$) “explains” only 35% of the actual value added growth. Using the ordinary IO table instead of the extended table thus yields an overestimation of no less than 24%, which indicates a clear bias. The overestimation amounts to 32% if the changes in the composition of the exports ($\Delta\mathbf{b}^e$) are also taken into account, next to the changes in the level of the exports $\Delta\varphi^e$.[15]

As a robustness check, the decompositions are also conducted with nominal prices (see Table 3.3). The overestimation was 24% for the change in the exports level ($\Delta\varphi^e$), and 30% when the change in the exports structure ($\Delta\mathbf{b}^e$) is added. The obvious reason for the smaller total bias with current prices is the fact that price inflation for Chinese domestic demand has been larger than that for Chinese exports. This leads to an underestimation of the importance of exports for real growth of GDP, and thus to an underestimation of the real bias.

Furthermore, note that all but two small changes in the self-sufficiency ratio of *processing trade* ($\Delta\mathbf{T}^P$), and in the relative difference of *processing trade* technology to the benchmark technology ($\Delta\Omega^P$) had the same sign compared to the contributions calculated with constant prices, while the relative size of the contributions is quite comparable going from Table 3.2 to Table 3.3. For these reasons, we prefer to further analyze the results of the analysis in constant prices only, although we warn for the larger uncertainty when using constant prices.

Table 3.3 Decomposition of China's value added growth in current prices for 2002-2007*

	Total	$\Delta\mathbf{c}$	$\Delta\mathbf{A}^n$	$\Delta\mathbf{t}^D$	$\Delta\mathbf{b}^f$	$\Delta\mathbf{b}^e$	$\Delta\varphi^f$	$\Delta\varphi^e$
With the ordinary IOM	14,418	-4.2	-2.1	-0.3	-1.3	-1.2	70.9	38.1
		$\Delta\mathbf{c}$	$\Delta\mathbf{A}^n$	$\Delta\mathbf{T}^O$	$\Delta\mathbf{b}^f$	$\Delta\mathbf{b}^e$	$\Delta\varphi^f$	$\Delta\varphi^e$
With the extended IOM	14,418	-3.9	-2.9	-0.8	-1.3	-2.2	75.2	30.7
		$\Delta\mathbf{T}^P$	$\Delta\mathbf{\Omega}^P$	$\Delta\mathbf{\Omega}^O$	$\Delta\mathbf{s}^O$	$\Delta\mathbf{s}^P$	$\Delta\boldsymbol{\tau}^O$	$\Delta\mathbf{t}^f$
		2.2	-0.3	2.1	-1.4	1.5	1.5	-0.3

* See Table 3.2 for an explanation of the captions.

[15] Note that the impacts of the volume changes of domestic final demand ($\Delta\varphi^f$) and exports ($\Delta\varphi^e$) are a multitude of the impacts due to the changes in coefficients. A comparable result was found for import growth by Pei et al. (2011a), where it was noted that the impacts of the structural changes in coefficients were relatively large for China, when compared to other countries.

3.4.3 Decomposition of value added embodied in "final" products

Before we decompose the value added changes of the individual industries (i.e., where the value added is generated), it is worth investigating the changes in value added as embodied in specific "final" products.

Table 3.4 Decomposition of value added growth embodied in "final" products*

		With the Ordinary IOM (%)				With the Extended IOM (%)			
Product	**Total growth**	$\Delta\mathbf{b}^f$	$\Delta\mathbf{b}^e$	$\Delta\varphi^f$	$\Delta\varphi^e$	$\Delta\mathbf{b}^f$	$\Delta\mathbf{b}^e$	$\Delta\varphi^f$	$\Delta\varphi^e$
1	-228	324	25	-246	-24	393	29	-298	-29
2	-27	146	78	-61	-73	154	81	-64	-76
3	-8	17	370	-51	-292	12	240	-33	-188
4	4	44	-21	36	85	40	-17	35	71
5	-3	-10	-600	52	682	7	460	-32	-519
6	824	20	-7	74	18	20	-7	75	16
7	411	-14	-14	9	116	-15	-13	9	106
8	585	13	-27	32	77	13	-21	34	60
9	243	18	4	21	55	19	4	21	48
10	97	-23	-27	21	135	-31	-23	29	121
11	27	35	-51	24	107	45	-51	31	105
12	207	-15	-21	28	116	-23	-24	44	132
13	74	-38	4	27	106	-41	4	29	105
14	273	9	43	3	51	10	36	3	46
15	226	0	-8	21	85	0	-6	22	66
16	828	18	7	44	29	19	7	48	26
17	862	40	8	37	17	43	6	39	14
18	520	24	-3	22	61	31	-2	28	41
19	1,340	0	40	8	65	1	21	15	43
20	119	4	-13	4	133	6	-10	4	109
21	161	26	-4	38	53	27	-2	40	36
22	96	7	3	89	2	7	2	88	2
23	7	-29	-228	267	123	-16	-93	155	64
24	3	-219	-4	242	2	-425	-5	469	3
25	2,125	3	0	97	1	3	0	100	1
26	445	4	-5	40	61	4	-5	41	61
27	504	-10	-9	124	10	-10	-9	119	9
28	531	34	0	68	0	35	0	69	0
29	484	-37	-7	139	12	-35	-6	133	11
30	1,619	-18	-28	104	44	-18	-24	103	38
Total	100%	-2.3	-2.1	66.0	42.8	-2.3	-3.8	70.1	34.6

* This table gives value added growth embodied in specific "final products", i.e. due to changes in the domestic final demand for and the exports of a certain product. The total growth of value added is in billion RMB, in 2002 constant prices; components' contributions are in %, which do not add to 100% as the impacts of coefficient changes are not included. See Table 3.2 for an explanation of the captions.

Analyzing such changesis more relevant in guiding policy formulation, because policies often take the form of stimulating the final demand of a specific product (e.g., of exports or government investments in infrastructure). Hence, equation (3-4b) is used for the ordinary IO model, and equation (3-7b) is applied to the extended case.

The results are given in Table 3.4.[16] Note that the aggregate growth of value added may be obtained by summing the "total" column. This yields again 12,350 billion RMB, as in Table 3.2, which is set at 100%.

The weighted totals of the other columns give the aggregate percentage contribution of each component, which are the same as in Table 3.2. Note also that we focus in Table 3.4 on the bias in estimating the causes of the changes in value added embodied in domestic final demand and exports by product. The contributions of the changes in coefficients, i.e. other components, are therefore omitted. As a consequence, the totals in the bottom row do not add to 100%.

The results show that 41% of the total value added growth is embodied in the final demands of just three products, namely *Construction* products (industry 25), *Other services* products (30), and *Telecommunication* related products (19). The value added embodied in the final demand for *Construction* products has increased the most (with 2,125 billion RMB, or 17% of the total value added growth). This growth is almost entirely due to the growth in the domestic final demand for this product. Note that the outcomes are nearly the same for the ordinary and the extended IO model. This should not come as a surprise because exports play only a very minor role for the non-tradeable products of the *Construction* industry.

The same applies (albeit to a lesser extent) for *Other services* products. Both IO models indicate that value added in industry 30 has grown primarily through the growth of the domestic final demand level ($\Delta\varphi^f$). But in the case of *Other services*, export growth ($\Delta\varphi^e$) also contributes with +40%, which is compensated by negative contributions of changes in the composition of domestic final demands ($\Delta\mathbf{b}^f$) and of exports ($\Delta\mathbf{b}^e$) of -20% and -25%, respectively. *Other services* are also characterized

[16] Except for product 1 (agriculture), product 3 (crude petroleum and natural gas products) and product 5 (non-ferrous mineral mining), which show opposite signs, the results using current prices are quite comparable with those of Table 3.4, especially for products 18-20. Due to a lack of space, the detailed results are omitted here, but are available upon request.

by ordinary production involving very little processing trade, which explains why the results for the two models are very much the same.

The story is completely different for the third largest contributor to value added growth, which is *Telecommunication* products (of industry 19). Value added as embodied in these products has grown by 1,340 billion RMB (which is 11% of the total value added growth). This massive growth is almost entirely caused by the changes in the exports of *Telecommunication* products. There is a stimulus from the growth of the overall export level as well as a stimulus from the shift in the composition of the exports towards telecommunication products. We have already seen in Table 3.1 that *Telecommunication* is an industry that plays a major role in processing trade. As a consequence, the results show substantial differences between the two models.

In the extended IO model this special character of *Telecommunication* is recognized, i.e. it contains a lot of processing trade, with close to zero domestic intermediate inputs and relatively little value added per RMB of output. The ordinary model works with the average structure for *Telecommunication*, with too much value added per RMB of output.

This is reflected perfectly by the results in Table 3.4. With the ordinary IO model, changes in the exports of *Telecommunication products* (i.e., level plus composition effect, or $\Delta\varphi^{e} + \Delta\mathbf{b}^{e}$) are responsible for 105% of the actual value added growth. When using the extended IO model, this is only 64%, which implies a very substantial overestimation of 63%. To a lesser extent, the same findings are found for the products of the other two "*high-tech*"industries (18 and 20).

3.4.4 Decomposition of the sector-specific growth of value added

In this subsection we study the effects of the changes in levels and coefficients on value added growth that has taken place in each and every industry. Note that this is the type of structural decomposition analysis that is usually carried out. Table 3.5 gives the outcomes when the ordinary IO table and equation (3-4a) are used, while Table 3.6 gives the results of the extended IO framework and equation (3-7a).

Table 3.5 Decomposition of sector-specific value added growth with the ordinary IO model*

		Changes in coefficients (%)					in levels (%)	
Sector	Total growth	$\Delta\mathbf{c}$	$\Delta\mathbf{A}^n$	$\Delta\mathbf{t}^D$	$\Delta\mathbf{b}^f$	$\Delta\mathbf{b}^e$	$\Delta\varphi^f$	$\Delta\varphi^e$
1	-27	718	1184	169	2156	368	-3356	-1139
2	-40	232	231	-8	43	29	-241	-187
3	-123	136	51	38	-5	16	-68	-68
4	-61	148	7	30	-11	-11	-32	-31
5	43	-43	-10	2	2	-20	101	67
6	744	6	27	-1	4	-5	53	17
7	423	8	6	10	-4	-11	19	72
8	283	3	15	3	9	-19	30	58
9	226	15	0	2	9	1	36	37
10	226	-9	-2	2	-6	-10	56	70
11	123	22	-23	1	4	-4	55	46
12	423	-35	-18	3	0	-6	69	87
13	593	9	36	1	-1	2	37	15
14	531	-16	-3	7	12	12	47	42
15	312	22	-3	6	3	0	33	40
16	810	13	3	5	11	4	39	26
17	600	-3	11	1	27	5	39	21
18	279	-24	3	11	17	3	36	55
19	1040	10	7	-6	0	26	10	53
20	98	-9	9	12	3	-8	8	86
21	247	-3	23	-11	12	1	39	40
22	628	-18	32	4	2	0	47	31
23	26	48	10	2	-1	-10	33	18
24	12	-29	-112	77	-50	-3	152	66
25	499	-11	-7	0	3	0	113	3
26	1338	24	5	-1	1	-1	40	32
27	433	-5	14	-7	-7	-7	97	15
28	288	-11	3	0	34	0	71	3
29	526	3	-14	-4	-20	-7	112	30
30	1850	8	-37	0	-8	-14	98	53
Total	100%	-1.4	-2.9	-0.1	-2.3	-2.1	66.0	42.8
WAIC	100%	9.9	11.7	2.5	7.4	5.3	38.3	24.9

*Changes in total sectoral value added, using equation (3-4a), are in billion RMB, in 2002 constant prices; the components' contributions are in % that add to 100%. WAIC = weighted absolute industry contribution.

Note: $\Delta\mathbf{c}$ = changes in value added coefficients; $\Delta\mathbf{A}^n$ = changes in *normalized* technical coefficients; $\Delta\mathbf{t}^D$ = changes in trade coefficients; $\Delta\mathbf{b}^f$ = changes in bridge coefficients; $\Delta\mathbf{b}^e$ = changes in export composition; $\Delta\varphi^f$ = change in level of final use; $\Delta\varphi^e$ = change in total export.

It is important to look at the decomposition of value added changes at the industry level, because its growth is very uneven across industries. It ranges from a

1,850 billion RMB increase in *Other services* (industry 30) to a 123 billion RMB decline of value added in *Crude petroleum and natural gas products* (industry 3).[17]

For industry 30 with the largest increase in value added, several observations in Table 3.6 are of interest. First, apart from the dominant role played by macro-economic factors (i.e., the growth of total domestic final demand and total exports, i.e., of $\Delta\varphi^f$ and $\Delta\varphi^e$), the impact of the changes in the normalized technical coefficients ($\Delta\mathbf{A}^n$) is sizeable. If only these coefficients had changed, value added in this industry would have fallen by 37% of the actual change (1,850 billion RMB). It indicates that *Other services* have become relatively less important, as intermediate inputs, compared to other products. Second, if the ordinary IO table is used (Table 3.5), the contribution of the export level ($\Delta\varphi^e$) plus the export composition ($\Delta\mathbf{b}^e$) is overstated by 38% (compared to Table 3.6). In money terms, this overestimation amounts to 185 billion RMB, which is a measurement error that is much larger than the total income changes in industries 3 (*Crude petroleum and natural gas products*) or 11 (*Petroleum processing, coking and nuclear fuel processing*). Third, the effect of the changes in the composition of the exports ($\Delta\mathbf{b}^e$) is more or less the same (approximately -15%) for both models, meaning that the composition of exports is undergoing a change in the direction of favoring other industries, such as industry 19 rather than industry 30.

Telecommunication equipment, computer and other electronic equipment (industry19) is the industry with the third largest growth of value added. Its distinguishing feature is the large positive contribution of the changes in the composition of exports ($\Delta\mathbf{b}^e$, 15% with the extended IO model and 26% with the ordinary IO model), which may be also observed with a few other industries.

[17] Again, we find similar results for Table 3.5 and Table 3.6 when using current prices. This is particularly true for products 18-20. However, there are four sectors (industry 1 through 4) showing opposite signs. The main reason is the difference in industry price increases. Prices of agriculture products, for instance, inflated with 63%, which is much faster than the inflation for other products from 2002 to 2007. As argued earlier, the analysis in constant prices gives a better description of the real overestimation of the contribution of exports when processing trade is not accounted for. The current price results for Tables 3.5 and 3.6 are available upon request.

Table 3.6 Decomposition of sector-specific value added growth with the extended IO model*

	Changes in coefficients (%)												Levels (%)	
Sector	$\Delta\mathbf{c}$	$\Delta\mathbf{A}^n$	$\Delta\mathbf{T}^O$	$\Delta\mathbf{b}^f$	$\Delta\mathbf{b}^e$	$\Delta\mathbf{T}^P$	$\Delta\mathbf{\Omega}^P$	$\Delta\mathbf{\Omega}^O$	$\Delta\mathbf{s}^O$	$\Delta\mathbf{s}^P$	$\Delta\boldsymbol{\tau}^O$	$\Delta\mathbf{t}^f$	$\Delta\varphi^f$	$\Delta\varphi^e$
1	698	1231	182	2192	346	44	-47	-85	1	1	-60	-30	-3442	-932
2	229	232	-1	43	39	9	-21	-18	0	0	-9	1	-259	-145
3	134	46	43	-5	17	3	-9	-4	0	0	-3	3	-75	-52
4	146	17	27	-12	-6	3	-9	-6	0	0	-5	0	-36	-19
5	-43	-19	15	2	-19	-2	6	3	1	-1	0	-3	110	50
6	6	26	-1	4	-5	0	0	1	0	0	0	0	54	14
7	8	6	5	-4	-10	-1	2	3	-3	2	5	0	22	64
8	3	16	1	10	-16	0	0	0	-6	3	3	2	33	51
9	15	-1	1	9	1	-1	1	2	-3	3	2	0	38	32
10	-9	-3	1	-7	-10	-2	5	5	-2	3	3	-1	64	53
11	22	-24	-3	4	-5	-2	5	5	1	0	2	-1	60	36
12	-34	-19	-1	-1	-8	-4	10	9	-3	3	3	-1	79	66
13	10	37	0	-1	1	-1	2	1	0	0	0	0	39	12
14	-16	-3	2	13	8	-2	6	6	0	0	4	0	53	29
15	23	-4	1	3	-1	-2	6	4	-4	3	2	0	37	32
16	13	2	6	11	3	-1	2	1	-1	2	1	-1	41	22
17	-3	11	1	27	3	-1	2	2	-2	2	1	-2	40	18
18	-24	3	6	20	-1	-1	9	2	-9	7	2	2	42	41
19	10	5	-8	1	15	-2	8	3	-3	10	-1	5	18	38
20	-8	5	18	2	-8	0	1	-2	25	-20	-2	-3	11	82
21	-3	24	-11	14	0	0	3	1	-2	0	4	-2	44	29
22	-17	32	4	2	-1	0	3	1	0	0	2	0	52	23
23	48	10	2	-1	-7	-1	1	2	0	0	-3	0	34	15
24	-30	-111	82	-57	-6	-4	5	7	0	0	1	2	160	50
25	-11	-7	0	3	0	0	0	0	0	0	0	0	113	3
26	24	5	0	1	-2	0	1	1	-1	0	1	-1	42	28
27	-6	12	-2	-7	-7	0	0	1	0	0	0	-2	98	13
28	-11	3	0	34	0	0	0	0	0	0	0	0	71	3
29	4	-14	-2	-21	-7	0	2	0	-1	0	2	-2	114	24
30	8	-37	0	-8	-15	1	3	1	-3	2	1	-1	102	44
Total	-1.0	-3.4	-0.7	-2.3	-3.8	-0.7	3.4	2.3	-1.6	1.9	1.5	-0.2	70.0	34.6
WAIC	9.5	11.1	2.3	1.9	7.2	4.4	1.9	1.3	1.1	1.2	1.0	0.8	38.8	19.2

* Changes in sectoral value added were obtained from using equations (3-8.1)-(3-8.3), the components' contributions are in % that add to 100%. WAIC = weighted absolute industry contribution.

Note: $\Delta\mathbf{c}$ = changes in value added coefficients; $\Delta\mathbf{A}^n$ = changes in *normalized* technical coefficients; $\Delta\mathbf{T}^O$ and $\Delta\mathbf{T}^P$ = changes in self-sufficiency coefficients of *O* and *P* type; $\Delta\mathbf{b}^f$ = changes in bridge coefficients; $\Delta\mathbf{b}^e$ = changes in export composition; $\Delta\mathbf{\Omega}^O$ and $\Delta\mathbf{\Omega}^P$ = changes in relative differences of *O* and *P* type technologies to the benchmark technology; $\Delta\mathbf{s}^O$ and $\Delta\mathbf{s}^P$ = changes in relative deviations of *O* and *P* type value added coefficients from the average value added coefficients; $\Delta\boldsymbol{\tau}^O$ = changes in shares of *O* products in total export by industry; $\Delta\mathbf{t}^f$ = changes in self-sufficiency coefficients for final demands; $\Delta\varphi^f$ = change in level of final use; $\Delta\varphi^e$ = change in total export.

This is an indication of a structural change favoring the exports of *Telecommunication* products. As we have seen before, when comparing the two frameworks, the overestimation of the role of export changes for value added growth in *Telecommunication* is substantial. The bias in the effect of the changes in the level and composition of the exports amounts to 49%. The other two "*high-tech*" industries (18 and 20) are of lesser importance in terms of value added growth than industry 19. The overestimation of the contribution of exports (level $\Delta\varphi^e$ plus composition $\Delta\mathbf{b}^e$) is 45% for industry 18, but only 5.0 per cent for industry 20.

It should be noted that the overestimation of the role of exports (when the ordinary IO model is used) is counterbalanced by the underestimation of the role of domestic final demands. Looking at the totals in the bottom rows of Table 4.5 and Table 4.6, we see that the average contribution of changes in domestic final demands (level $\Delta\varphi^f$ plus composition $\Delta\mathbf{b}^f$) is 68% if the extended model is used and 64% if the ordinary model is used. This is a small underestimation of the importance of the growth of domestic final demand of 6.0 per cent. For the three "*high-tech*" industries, however, the underestimation is much larger, namely 15% in industries 18 and 20, and 47% in industry 19.

This should come as no surprise. When calculating the effects of changes in the domestic final demands, the production structure that corresponds to *Other production* should be used (as is the case in the extended model). *Other production* relies much more on domestic inputs and yields much more value added per unit of domestic final demand. So, underestimation is to be expected when the ordinary model is used, which wrongly also includes the production of processing exports. For most industries, this error is relatively minor. For industries with much processing trade, however, the *Other production* structure and the total of *Other production* and *Production for processing exports* are expected to differ substantially. Underestimation in the case of domestic final demands and overestimation in the case of exports is thus anticipated.

In fact, *Instruments, meters, cultural and office machinery* (industry 20) also presents an interesting feature in the sense that the relative difference coefficient of *Other production* to the benchmark value added coefficient (i.e., $\Delta\mathbf{s}^O$) contributes 25% to its value added growth; while the relative difference coefficient of *Processing* *exports* to the benchmark value added coefficient (i.e., $\Delta\mathbf{s}^P$) gives a negative contribution of 20% to the income growth, which is in line with the sharp increase in the share of processing imports in this sector from 11% in 2002 to 50% in 2007 (see Table 3.1).

Finally, we would like to stress that the average results in the row "total" do not sketch the full picture. That is, present data suggest that only the contributions of changes in final demands (domestic and exports) matter and that the other effects are minor. In fact, there is quite a lot of variation in the contributions of other effects, but when averaged over the industries they often cancel each other out. To substantiate the importance of the variation among industries, and to underscore that the contributions of coefficient changes to value added growth are more important than the average results suggest, we calculate for each of the components its "weighted absolute industry contribution" (WAIC, see also Pei et al., 2011a).[18] The underlying idea is to neutralize the effect of having positive and negative industry impacts that disappear in the row labeled "total".

The WAICs in Table 3.5 and 3.6 show that large variations are hidden when average effects are used. For example, the average contribution of the macro-economic factors (i.e., of $\Delta\varphi^f$ and $\Delta\varphi^e$) to value added growth at the sectoral level is reduced from more than 100% to approximately 60%. The impact of neglecting the compensating effect of negative and positive values is relatively even larger in the case of the contributions of coefficient changes to value added growth (although smaller in magnitude). For example, the role of changing value added coefficients $\Delta\mathbf{c}$ is almost negligible in Table 3.6 (-1.0 per cent), when the simple average contribution is taken, but it is quite substantial (9.5 per cent) when the WAIC is used. The same applies for the technical coefficients $\Delta\mathbf{A}^n$, contributing -3.4 per cent on average in Table 3.6, but as much 11% when measured with the WAIC.

[18] That is, let Δ_{iq} indicate the change of value added (in billion RMB) in industry *i* due to a change in component *q*, then WAIC is obtained as $\Sigma_i \left|\Delta_{iq}\right| / \Sigma_i \Sigma_q \left|\Delta_{iq}\right| \times 100\%$. Note that WAIC corresponds to the "*weighted absolute percentage error*" (i.e., WAPE, see de Mesnard and Miller, 2006).

3.5 Concluding remarks

This study contributes to the literature in two ways: empirically and methodologically. The presence of processing trade, i.e. imported inputs that may only be used for the production of exports, requires a change in the conventional accounting framework. In this chapter we have used China's extended input-output tables that distinguish processing trade from ordinary exports. Contrary to the prevailing opinion that exports contribute much to China's value added growth, this study shows that this importance is overstated. The impact of changes in exports (both as regards its level and composition) on the growth in GDP is overestimated by 32% if processing trade is not properly included in the model. Even more striking results are found at the level of individual products and industries. This holds in particular for *Telecommunication*, the most important of the three "*high-tech*" industries. Our results indicate that "sophisticated exports" like *Telecommunication*, are less sophisticated than they appear at first sight, if they are based on much foreign value added (Xu, 2010; Xu and Lu, 2009).

Besides the conventional decomposition of sectoral value added growth, we also investigate the importance of product-specific causes, i.e. of domestic final demand growth by product and of foreign export growth by product. Looking from this new angle, the following conclusion can be drawn. From an income-generating point of view, processing trade is much less "profitable" than ordinary trade.[19] This underscores a policy of "industry upgrading", which aims to improve the position of China's industries in the global value added chain.

Methodologically, three refinements are made in applying structural decomposition analysis, as we explicitly take into account the substitution between primary inputs and intermediate inputs, among intermediate inputs, and between a "home" origin and a "foreign" origin of intermediate inputs. It is worth noting that,

[19] The "*First China Achievement's Expo for Self-innovated Auto Technology and Products*" in 2010 was held to show the achievements that have been made since 1953. One of the experts (Mr. BingjinXu,*President of the China Europe Association For Economic and Technical Cooperation*), however, expressed a rather pessimistic view, pointing at the fact that China possesses less than 30% of the intellectual property rights in the car industry. Specifically, on 20 July 2010, Bingjin Xu spoke to the *CCTV News 1+1* that, the whole car supply chain is beyond the control of domestic enterprises, except for the assembly activities. In other words, the superficial prosperity induced by processing trade needs to be investigated with more sophisticated methods, as shown by our findings. Comparable empirical findings can befound in the volume edited by Feenstra and Wei (2010).

the extended SDA formula can easily be reduced to the standard form, and can be adopted for other developing countries with considerable processing trade, such as Mexico (see Johnson and Noguera, 2012).

Appendix

3.A Chinese input-output table: Sector classifications

IO sector	Description	IO Code (2002/07)*
1	Agriculture	1
2	Coal mining, washing and processing	2
3	Crude petroleum and natural gas products	3
4	Metal ore mining	4
5	Non-ferrous mineral mining	5
6	Manufacture of food products and tobacco processing	6
7	Textile goods	7
8	Wearing apparel, leather, furs, down and related products	8
9	Sawmills and furniture	9
10	Paper and products, printing and record medium reproduction	10
11	Petroleum processing, coking and nuclear fuel processing	11
12	Chemicals	12
13	Nonmetal mineral products	13
14	Metals smelting and pressing	14
15	Metal products	15
16	Common and special equipment	16
17	Transport equipment	17
18	Electric equipment and machinery	18
19	Telecommunication equipment, computer and other electronic equipment	19
20	Instruments, meters, cultural and office machinery	20
21	Other manufacturing products	21, 22
22	Electricity and heating power production and supply	23
23	Gas production and supply	24
24	Water production and supply	25
25	Construction	26
26	Transport, warehousing and post	27, 28
27	Education, culture and related	35, 39, 41
28	Health service, social guarantee and social welfare	40
29	Accommodation and related	31, 33
30	Other services	29, 30, 32, 34, 36-38, 42

* The IO Codes (2002/07) are for the 42-sector benchmark classification scheme as released by NBS China. Details for the 42-sector classification are available upon request.

CHAPTER 4

INTERREGIONAL TRADE, FOREIGN EXPORTS AND CHINA'S REGIONS IN PRODUCTION CHAINS[1]

4.1 Introduction

Economists have long recognized that the spatial dimension of economic activities is important (Fujita et al., 1999). Another reason to investigate interregional interdependencies is that they have real implications for regional policy programs. Because of China's vast area and huge population, interregional equity has been a major concern to its central government, in particular after the relative failure of its "stepladder strategy" toward development (Brun et al., 2002).[2] According to that strategy, fast-growing coastal regions would spillover growth to interior regions through interregional trade and technological transfers (Ying, 2000; Fu, 2004; Groenewold et al., 2007).

Interregional spillovers that run through markets will be tied to interregional transactions, such as the interregional product flows that are recorded in input–output (IO) tables. For example, as foreign exports stimulate demand for manufactures in coastal regions, related raw materials are needed from interior regions. Such materials ultimately generate more income in interior regions. However, local protection undermines the potential growth spillovers.[3] To tackle the potential consequences of the regional disparities, China launched several regional development programs. Large amounts of investments are involved in these programs. Thus, accurate

[1] This chapter is a substantially revised version of the conference paper "Trade, supply chains and regional income disparity in China", which was presented at *19th International Input-Output Conference*, Alexandria, the *4th Spanish Input-Output Conference* in Madrid, and *ARTNeT Workshop* in Bangkok (co-authored with Jan Oosterhaven and Erik Dietzenbacher, see Pei et al., 2011b).

[2] In 2010, for example, regional gross domestic product (GDP) ranged from 50.7 billion Renminbi (RMB) in Tibet to 4.6 trillion RMB in Guangdong Province. The differences in 2010 were also huge when measured by GDP per capita, ranging from 13.2 thousand RMB in Guizhou Province to 74.5 thousand RMB in Shanghai.

[3] This might be why China faces serious regional disparity problems. See discussions in Jian et al. (1996), Raiser (1998), and Zhang (2001).

measures of the impact of regional investment programs in the region itself and in the Rest of China (RoC) are required.

To account for the income formation in an interregional context, we use the interregional input–output (IRIO) model (Isard, 1951; Oosterhaven, 1981; Miller and Blair, 2009), with China grouped into eight regions. This is the only model that is able to examine interregional interindustry interdependencies (i.e., to distinguish intraregional effects from interregional spillovers at the level of individual industries; Oosterhaven et al., 2001; Zhang and Zhao, 2005). We decompose the complex framework of intraregional effects and interregional spillovers using an additive decomposition methodology (Oosterhaven, 1981; Miller and Blair, 2009).

At the same time, the importance of foreign exports for China's tremendous economic growth has been investigated extensively (Akyüz, 2011; Jarreau and Poncet, 2012; Pei et al., 2012). It seems to be a well-studied subject, and the mechanisms, such as comparative advantage, economies of scale, and technology transfer, have been illustrated clearly (for recent documentation, see Melitz and Trefler, 2012). Furthermore, foreign exports contribute to the improvement of aggregate industry productivity and economic growth (Feder, 1982; Frankel and Romer, 1999; Melitz, 2003).[4] China's coastal regions obviously benefit significantly from foreign exports, but what is not obvious is whether this also holds true for interior regions. This important dimension of foreign exports has not been investigated properly thus far. From a production chain perspective, which regions are upstream and which are downstream?[5] We argue that interior regions are upstream and, because of interregional product transactions, are intimately integrated with downstream coastal regions.

To address these research questions, this study employed China's 2002 and 2007 IRIO tables with processing and assembling (P&A) exports separated. The distinction between ordinary exports and processing exports is of prime importance (Jarreau and Poncet, 2012; Pei et al., 2012) and is made possible by incorporating detailed customs

[4] Spatial concentration of foreign exports in the coastal regions also has implications for the regional disparity problem (Sun and Parikh, 2001; Zhang, 2001). Given the primary focus of this study, we do not investigate the disparity problem explicitly.

[5] In line with Antràs et al. (2012), the upstream regions are those that have a relatively longer distance to final use in the production chain. Prior contributions (e.g., Dietzenbacher and Romero, 2007) focusing on production chains have shed light on the importance of sequencing, using a different terminology—namely, average propagation lengths (APL).

data. Studies that fail to make the distinction will exaggerate the backward effects of foreign exports on the Chinese economy (Dietzenbacher et al., 2012). This novel dataset enables investigation of the changing nature and significance of indirect income effects in general and those due to foreign exports in particular.

Empirically, two distinct but inherently related investigations were conducted. First, interregional indirect income effects were estimated by means of the so-called normalized indirect income multiplier, which can be applied to a whole series of regional policy programs. Second, interregional income spillover effects due to foreign exports were studied as a specific application of interregional income multipliers. Furthermore, we proposed an index—namely "net interregional income spillovers" due to foreign exports—to account for the position of China's individual regions in the global value chain. The results offer a way to assess certain national investment programs on the one hand and to explain the important role that foreign exports play in the Chinese economy on the other hand.[6]

The rest of this chapter is structured as follows. Section 4.2 presents the data and a preliminary empirical analysis of the two research questions. Section 4.3 proposes the IRIO model to explicitly deal with interregional interdependencies. Section 4.4 empirically analyzes these interregional interdependencies: first, by means of dimensionless indirect income multipliers; and second, by applying them to "ordinary" foreign exports (i.e., excluding P&A exports) by region. The last section concludes and discusses.

4.2 Data processing and preliminary analysis

First, we discuss the data problems and the solution (i.e., the modification of China's IRIO table with P&A exports separated). Second, we discuss direct interregional interdependencies using the aggregate input structures of China's eight regions. Finally, we present the spatial concentration of foreign exports in China's coastal regions.

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[6] In the same vein, investment programs and exports also have implications for the regional disparity problem. (See Yang and Lahr, 2008; He and Duchin, 2009; and Jiang, 2011, who adopt a comparable methodology to investigate China's regional disparity problem explicitly.) Given the primary focus of this study, we do not investigate the disparity problem explicitly.

4.2.1 China's IRIO table with P&A exports separated

The primary source data are China's IRIO tables constructed by the State Information Center of China (SIC) in collaboration with the National Bureau of Statistics of China (NBS) for 2002 and 2007 (Zhang and Qi, 2012).[7] The IRIO tables include 17 sectors, covering eight regions (see Appendices 4.A and 4.B for the classification of the regions and sectors).[8]

Figure 4.1 Layout of China's 2002/07 interregional input-output table*

	Intermediate deliveries				Domestic final use			STK	Export	TO
	$\mathbf{Z}^{11}$	$\mathbf{Z}^{12}$	$\cdots$	$\mathbf{Z}^{1R}$	$\mathbf{F}^{11}$	$\cdots$	$\mathbf{F}^{1R}$	$\boldsymbol{\Delta}^{1}$	$\tilde{\mathbf{e}}^{1}$	$\mathbf{x}^{1}$
	$\mathbf{Z}^{21}$	$\mathbf{Z}^{22}$	$\cdots$	$\mathbf{Z}^{2R}$	$\mathbf{F}^{21}$	$\cdots$	$\mathbf{F}^{2R}$	$\boldsymbol{\Delta}^{2}$	$\tilde{\mathbf{e}}^{2}$	$\mathbf{x}^{2}$
	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
	$\mathbf{Z}^{R1}$	$\mathbf{Z}^{R2}$	$\cdots$	$\mathbf{Z}^{RR}$	$\mathbf{F}^{R1}$	$\cdots$	$\mathbf{F}^{RR}$	$\boldsymbol{\Delta}^{R}$	$\tilde{\mathbf{e}}^{R}$	$\mathbf{x}^{R}$
IM	$(\mathbf{m}^{Z1})'$	$(\mathbf{m}^{Z2})'$	$\cdots$	$(\mathbf{m}^{ZR})'$	$(\mathbf{m}^{f1})'$	$\cdots$	$(\mathbf{m}^{fR})'$	0	0	m
VA	$(\mathbf{v}^{1})'$	$(\mathbf{v}^{2})'$	$\cdots$	$(\mathbf{v}^{R})'$						
TI	$(\mathbf{x}^{1})'$	$(\mathbf{x}^{2})'$	$\cdots$	$(\mathbf{x}^{R})'$						

* TO = total output; VA = value added; IM = foreign imports; STK = changes in inventories; TI = total input. A prime indicates the transposition of a vector.

Figure 4.1 presents the layout of China´s 2002/07 IRIO tables.[9] The 17-element vectors $\mathbf{x}^r$, $\mathbf{v}^r$, $\mathbf{m}^{Zr}$, $\tilde{\mathbf{e}}^r$ and $\boldsymbol{\Delta}^r$ denote (for region *r*) , respectively, total outputs/inputs, value added, imports from the Rest of the World (RoW), gross exports to the RoW, and changes in inventories. Superscripts *r* and *s* indicate region-specific values, with *rs* indicating a flow from region *r* to region *s*. Furthermore, $\mathbf{Z}^{rr}$ gives the 17×17 matrix of intraregional intermediate deliveries for region *r*, and $\mathbf{Z}^{rs}$ is the

[7] Note that they use the term multiregional input–output (MRIO) table, which differs from the IRIO table (Miller and Blair, 2009). Only the IRIO table has full (albeit often estimated) information of the deliveries of industry *i* in region *r* to industry *j* in region *s*. It is worth stressing that there is a 1997 IRIO table for China, which is constructed by SIC and the Institute of Developing Economies (IDE-JETRO) in Japan. The reasons not to include it in this study are twofold. First, the compilation methods are not entirely comparable. And second, the 1997 IRIO table does not differentiate imports from domestic products.

[8] We acknowledge that several institutions, both within and outside China, are constructing Chinese IRIO tables (e.g., the Development Research Centre of the State Council of China). Despite the different definition of regions, the methodologies are comparable according to the literature. However, one major advantage of the dataset that we use here is that it is semi-official and publicly accessible.

[9] There is one more column, namely *discrepancies*. Because they are both small and economically trivial, we do not discuss them explicitly in this study. In addition, they are assumed to have no import content.

17×17 matrix of interregional intermediate exports from r to s. The 17×4 matrix $\mathbf{F}^{rr}$ gives the intraregional final demands, with the following four categories: rural household consumption, urban household consumption, government expenditure, and gross fixed capital formation. In addition, $\mathbf{F}^{rs}$ is the 17×4 matrix of interregional exports from region r to final demand in region s, with the same four categories as in $\mathbf{F}^{rr}$. Finally, $\mathbf{m}^{fr}$ is (for region r) the four-element vector with imports for final demand purposes, and the scalar m indicates total imports from the RoW.

Processing exports play an important role in China's foreign exports (e.g., the proportion of processing exports to total exports was 55% (51%) in 2002 (2007); see NBS). Unlike ordinary exports, however, processing exports use few domestic intermediate inputs. Therefore, it is necessary to explicitly distinguish these two types of exports (Jarreau and Poncet, 2012; Pei et al., 2012). Two types of processing exports exist: (i) processing exports with purchased imported products, for which domestic firms possess the ownership, and (ii) P&A exports, with ownership by foreign companies. These two types make up roughly 90% of the total processing exports. As processing imports are exempted from tax, customs agencies keep track of the entire production process, which ensures the data availability. It is worth stressing that P&A exports use P&A imports that are shipped (tax-free) to China and will be shipped back to the foreign counterparts after assembling (i.e., foreign ownership remains unchanged in the whole production process). So, hardly any domestic intermediates are involved in this case (for a more detailed interpretation, see Pei et al., 2011).

Thus, the P&A exports should be separated from gross exports before any analysis is conducted. This is done by using detailed P&A exports data by province and by commodity from China customs and a concordance table to match the customs data to IO sectors. Furthermore, to reconcile the data, we add an additional column to Figure 4.1, namely P&A (i.e., P&A exports).[10] The ordinary foreign exports are

[10] Ideally, the IRIO table should be partitioned into two parts—namely, "processing exports" and "others"—as is done in Pei et al. (2012) for a national IO table. However, not all necessary data are available at the regional level. Little information is available even for the processing and assembling imports by region, let alone the value added data for the part of a sector that is involved in P&A exports. We thus need to keep in mind that the present split-up of P&A exports from gross exports is only a half-way treatment. The modified tables are believed to be better than the original ones, in particular when estimating the economy-wide impact of foreign exports. To test this assertion, we estimate the total national value added generated by total exports (both processing exports and non-processing exports) for China in three ways. First, using the partitioned national IO table (i.e., the 2007 partitioned

obtained by subtracting P&A exports from gross export values. The resulting IRIO framework appears in Figure 4.2.

Figure 4.2 Layout of China's IRIO table with P&A exports separated*

	Intermediate deliveries				Domestic final use			STK	Export	PAX	TO
	$\mathbf{Z}^{11}$	$\mathbf{Z}^{12}$	$\cdots$	$\mathbf{Z}^{1R}$	$\mathbf{F}^{11}$	$\cdots$	$\mathbf{F}^{1R}$	$\boldsymbol{\Delta}^{1}$	$\mathbf{e}^{1}$	$\mathbf{e}^{pa1}$	$\mathbf{x}^{1}$
	$\mathbf{Z}^{21}$	$\mathbf{Z}^{22}$	$\cdots$	$\mathbf{Z}^{2R}$	$\mathbf{F}^{21}$	$\cdots$	$\mathbf{F}^{2R}$	$\boldsymbol{\Delta}^{2}$	$\mathbf{e}^{2}$	$\mathbf{e}^{pa2}$	$\mathbf{x}^{2}$
	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$	$\cdots$
	$\mathbf{Z}^{R1}$	$\mathbf{Z}^{R2}$	$\cdots$	$\mathbf{Z}^{RR}$	$\mathbf{F}^{R1}$	$\cdots$	$\mathbf{F}^{RR}$	$\boldsymbol{\Delta}^{R}$	$\mathbf{e}^{R}$	$\mathbf{e}^{paR}$	$\mathbf{x}^{R}$
IM	$(\mathbf{m}^{Z1})'$	$(\mathbf{m}^{Z2})'$	$\cdots$	$(\mathbf{m}^{ZR})'$	$(\mathbf{m}^{f1})'$	$\cdots$	$(\mathbf{m}^{fR})'$	0	0	0	m
VA	$(\mathbf{v}^{1})'$	$(\mathbf{v}^{2})'$	$\cdots$	$(\mathbf{v}^{R})'$							
TI	$(\mathbf{x}^{1})'$	$(\mathbf{x}^{2})'$	$\cdots$	$(\mathbf{x}^{R})'$						e^{pa}	

* TO = total output; VA = value added; STK = changes in inventories; TI = total input; PAX = processing and assembling exports. Note: $\mathbf{e}^{r} + \mathbf{e}^{par} = \tilde{\mathbf{e}}^{r}$. The scalar e^{pa} gives the total value of P&A exports.

4.2.2 A sketch of transactions among regions

For our analysis, it is important to measure the interregional interdependencies accurately. Table 4.1 gives the aggregate input structures for the total production of the 17 sectors. It provides information about the direct intraregional deliveries and the direct interregional spillovers.

First, the bottom row in the upper panel of Table 4.1 shows that the aggregate value-added coefficients can be roughly grouped into two categories. The four coastal regions have relatively low aggregate value-added coefficients in 2007, ranging from 28.2% in the East Coast (EC) to 31.4% in the Northern Municipalities (NM).

IO table used in Pei et al., 2012) to calculate the total national value added generated by gross exports yields 6,034 billion RMB (which we take as the benchmark outcome). Second, using China's official national IO table to calculate the total national value added generated by gross exports yields 7,380 billion RMB (which is a 22% overestimation). Third, using the same official national IO table to calculate the total national value added generated by ordinary exports (i.e., gross exports less P&A exports) yields 6,943 billion RMB (which is a 15% overestimation). Thus, the results support our choice (i.e., at the national level, focusing on ordinary exports yields better results than focusing on gross exports).

Table 4.1 Aggregate input coefficients (in %) for the business sector by region*

2007 Business sector in	NE	NM	NC	EC	SC	CR	NW	SW	Tot.
Deli. fr. NE	50.3	2.7	1.6	0.9	1.0	1.1	1.3	1.1	**5.1**
Deli. fr. NM	1.0	38.6	2.8	0.5	0.4	0.5	1.0	0.3	**3.0**
Deli. fr. NC	1.6	8.5	54.3	1.2	1.2	2.7	3.4	0.9	**10.3**
Deli. fr. EC	0.6	1.2	1.1	52.4	3.7	3.2	1.6	1.0	**14.1**
Deli. fr. SC	1.6	2.0	1.2	1.5	44.4	2.2	3.0	4.6	**8.5**
Deli. fr. CR	0.7	1.4	3.1	3.8	2.8	48.1	2.4	1.2	**10.5**
Deli. fr. NW	0.9	1.4	1.5	1.3	1.2	1.5	39.9	1.7	**3.6**
Deli. fr. SW	0.5	0.4	0.6	0.7	2.0	0.7	1.6	46.9	**4.9**
Tot. Rest of China	**6.9**	**17.6**	**11.7**	**9.8**	**12.3**	**11.9**	**14.4**	**10.8**	**-**
Tot. China	**57.2**	**56.2**	**66.0**	**62.2**	**56.7**	**60.0**	**54.3**	**57.7**	**60.0**
From RoW	**7.6**	**12.4**	**4.3**	**9.6**	**12.0**	**4.1**	**5.4**	**4.5**	**7.5**
Value added	**35.2**	**31.4**	**29.6**	**28.2**	**31.3**	**35.9**	**40.2**	**37.8**	**32.5**
2002 Business sector in									
Deli. fr. NE	49.1	2.8	1.3	0.2	0.3	0.4	1.4	0.6	**5.0**
Deli. fr. NM	0.5	36.4	1.6	0.1	0.3	0.1	0.4	0.1	**2.4**
Deli. fr. NC	0.8	7.0	48.1	0.4	0.4	0.8	1.6	0.3	**7.5**
Deli. fr. EC	0.6	2.0	2.0	51.9	1.8	3.6	2.1	1.0	**13.5**
Deli. fr. SC	1.1	1.9	1.2	1.2	41.3	1.5	3.3	2.8	**8.1**
Deli. fr. CR	0.8	2.4	2.8	1.7	1.4	48.5	2.6	1.0	**10.0**
Deli. fr. NW	0.6	0.8	0.6	0.4	0.3	0.5	40.0	0.5	**2.7**
Deli. fr. SW	0.6	0.7	0.5	0.3	1.1	0.4	2.5	48.5	**5.2**
Tot. Rest of China	**4.8**	**17.7**	**10.1**	**4.3**	**5.7**	**7.3**	**13.9**	**6.3**	**-**
Tot. China	**53.9**	**54.1**	**58.2**	**56.2**	**47.0**	**55.8**	**53.9**	**54.8**	**54.3**
From RoW	**4.3**	**9.5**	**3.0**	**10.2**	**16.2**	**1.4**	**2.3**	**1.4**	**6.8**
Value added	**41.8**	**36.4**	**38.8**	**33.7**	**36.8**	**42.8**	**43.9**	**43.8**	**38.9**

* Deli. fr. means deliveries from. Tot. = total. Tot. RoC stands for "total from the Rest of China," giving the aggregate interregional import coefficients from the RoC. From RoW gives the aggregate foreign imported input coefficients. Appendix 4.C provides the aggregate input structures at industry level.

This reflects the downstream nature of these regions. Typically, downstream regions produce final products, which depend largely on intermediate inputs per unit of output. Because the value-added coefficient equals one less the sum of intermediate input coefficients (including those for regional and foreign imports), the value-added coefficients are relatively small. Upstream regions typically produce primary goods that require relatively few intermediate inputs but more value added. The large aggregate value-added coefficient is an indication of production activities that occur in the early phase of the production chain.

Observe that the aggregate value-added coefficients in all regions decreased from 2002 to 2007. The biggest absolute change occurred in the North Coast (NC), which realized a 9.2 percentage point decrease, followed by a 6.9 percentage point decrease in Central Regions (CR). Clearly, smaller aggregate value-added coefficients (associated with larger aggregate intermediate input coefficients and/or larger aggregate foreign import coefficients) indicate more complicated (i.e., roundabout) production processes, which holds true for all China's regions, regardless of whether they are coastal or interior regions.

Second, regarding the dependence on foreign imports, a distinction between three coastal regions (NM, EC, and SC) and the RoC is clear (see the row "From RoW"). Note that the distinction was larger in 2002 and that EC and SC had larger aggregate foreign import coefficients than aggregate interregional import coefficients in 2002 (see the row "Tot. Rest of China"). All regions except for EC and SC show an increase in their aggregate foreign import coefficients from 2002 to 2007. This indicates a convergence among China's regions in terms of foreign import dependence (as reflected by the *standard deviation* of the aggregate foreign import coefficients per region that went from 5.4 in 2002 to 3.5 in 2007).

Third, for intraregional deliveries (see the values on the diagonal), aggregate coefficients range from 38.6% in NM to 54.3% in NC in 2007. From 2002 to 2007, the aggregate coefficients of intraregional deliveries in NC and SC increased significantly. In contrast, CR, Northwest (NW), and Southwest (SW) experienced a decline in aggregate intraregional input coefficients. These increases or decreases of the aggregate intraregional input coefficients lead to corresponding changes in their intraregional indirect multipliers.

Finally, the size of the direct interregional spillovers for each region appears in the row "Tot. Rest of China." NM has significant interregional spillovers, as its aggregate interregional import coefficient is the highest (i.e., 17.6% in 2007). This means that to produce one unit of typical output in NM, 17.6% of intermediate inputs are sourced directly from the RoC. Furthermore, all regions increased their external dependency on the RoC (with an exception for NM) from 2002 to 2007. This leads to larger interregional spillovers of all kinds of regional impulses, such as investment or foreign exports. This finding makes the IRIO modeling even more important.

4.2.3 Foreign exports are spatially concentrated in coastal regions

Previous studies suggest that foreign exports are important driving forces for China's economic growth (Akyüz, 2011; Pei et al., 2012), so it is necessary to investigate the effects of foreign exports on regional economies in China. Before the impacts of the foreign exports are studied, we will first discuss the direct regional shares in the foreign exports per industry.[11]

Table 4.2 presents the 10 most important exporting industries and shows that they are spatially concentrated in the coastal regions EC and SC. In almost all the large exporting sectors, EC and SC combined have a majority share. This is true, for example, for both the large traditional *textile and wearing apparel* sector (industry 4 with EC and SC together producing 76.5% of China's *textile* exports) and the relatively sophisticated *electronic products*sector (industry 12 with EC and SC together producing 84.6% of China's *electronic products* exports) in 2007. It is found that EC and SC have a strong foreign exports focus and strongly depend on foreign imports (see Table 4.1). So these two regions are relatively more open from an international perspective.

Moreover, EC overtook SC in 2007 in terms of regional shares of foreign exports. Notably, three of the four of China's coastal regions experienced an increase in their regional share of foreign exports. Taking into account the 30% average annual growth rate of foreign exports in China during this period (see NBS), it is clear that most coastal regions rely heavily on foreign markets. This is in line with the observations made in Table 4.1 regarding the relatively high foreign import dependence of the coastal regions.

[11] Table 4.2 uses the ordinary foreign exports data (i.e., P&A exports are deducted from gross exports a priori). A similar pattern emerges if gross exports are used, however. Note that the ordinary foreign exports data are used in all empirical analyses throughout this study, unless otherwise stated.

Table 4.2 Regional shares in foreign exports per sector (in %) and industry shares in national exports (in %)*

2007	NE	NM	NC	EC	SC	CR	NW	SW	**Export share**
3	6.0	2.9	27.0	13.3	39.2	3.8	5.1	2.6	3.5
4	4.5	2.4	10.6	60.6	15.9	3.3	1.1	1.7	11.9
7	6.9	2.8	11.1	22.7	41.8	7.3	3.7	3.6	11.6
9	7.9	4.8	11.7	36.5	19.7	7.7	8.4	3.4	10.0
10	6.0	5.1	3.1	55.0	20.3	4.1	3.2	3.2	5.4
11	4.9	4.0	2.0	46.9	32.2	5.6	1.0	3.4	5.6
12	1.7	10.8	0.9	57.9	26.7	0.6	0.4	0.9	26.7
13	1.6	4.2	1.5	27.4	63.0	1.4	0.3	0.6	3.9
16	4.4	16.0	21.8	21.2	23.6	5.4	6.2	1.3	7.4
17	2.6	51.7	4.8	24.3	2.5	3.2	7.6	3.3	3.6
Total	**4.4**	**8.1**	**8.8**	**41.9**	**26.8**	**3.8**	**4.1**	**2.1**	
2002									
3	9.1	5.6	30.7	15.6	26.7	4.6	3.0	4.8	3.3
4	2.8	3.2	11.2	49.5	26.9	3.6	1.3	1.4	20.2
7	7.4	6.5	10.8	27.9	32.8	7.9	2.3	4.4	8.3
9	6.1	3.9	10.6	29.2	31.8	8.6	4.6	5.1	5.6
10	2.7	1.6	4.2	20.4	67.5	1.4	0.8	1.4	7.3
11	8.0	4.9	5.3	39.7	31.8	3.8	1.0	5.6	2.7
12	3.0	10.0	2.6	34.5	47.3	0.7	0.3	1.6	26.6
13	4.9	3.2	5.4	17.4	62.1	5.0	0.7	1.3	4.6
16	5.4	5.4	5.1	26.7	49.6	3.8	2.8	1.2	7.2
17	4.7	34.0	2.7	39.0	14.3	1.2	0.9	3.2	2.8
Total	**4.8**	**6.7**	**7.9**	**32.2**	**41.2**	**3.4**	**1.5**	**2.3**	

* See Appendix 4.B for the meaning of the industry numbers. (Here we present the 10 largest foreign exporting sectors.) "Export share" gives the industry shares in the total national foreign exports (in %). Values per exporting industry are regional shares in foreign exports per industry (per row the percentages of the eight regions add to 100). Source: Authors' calculation based on China's 2002 and 2007 IRIO tables.

Thus, this preliminary empirical analysis provides a sketch about direct interregional interdependencies, as well as the spatial concentration of foreign exports in coastal regions (both at the aggregate level and at the industry level). At the same time, to account for the total effects of, for example, a 1 billion RMB investment stimulus in one particular region to both itself and the RoC, indirect intraregional effects and interregional spillovers need to be added to the direct impacts. This also holds true for the value-added effect of foreign exports. To study these indirect effects, IRIO analysis is the proper tool.

4.3 The Methodology

The fundamental IO equation will serve as the starting point: (i) supply follows demand (i.e., total output equals intermediate demand plus final demand, so $\mathbf{x} = \mathbf{Zi} + \mathbf{y}$) and (ii) intermediate demand is determined by total output using fixed intermediate input coefficients (i.e., $\mathbf{Zi} = \mathbf{Ax}$). Thus, we have the following:

$$\mathbf{x} = \mathbf{Zi} + \mathbf{y} = \mathbf{Ax} + \mathbf{y} \qquad (4\text{-}1)$$

where $\mathbf{Z}$ is the matrix of intermediate deliveries, $\mathbf{i}$ is the summation vector of appropriate length, $\mathbf{A}$ is the matrix of input coefficients, $\mathbf{x}$ is the vector of gross output, and $\mathbf{y}$ is the vector of final demand. In an IRIO framework with N sectors and R regions, the dimensions of $\mathbf{A}$ and $\mathbf{Z}$ are $NR \times NR$, and those of the vectors $\mathbf{x}$, $\mathbf{y}$, $\mathbf{\Delta}$, $\mathbf{e}$, and $\mathbf{e}^{pa}$ are NR. The matrices and vectors can all be partitioned according to Figure 4.2. We then have the following:

$$\mathbf{A} = \begin{pmatrix} \mathbf{A}^{11} & \mathbf{A}^{12} & \cdots & \mathbf{A}^{1R} \\ \mathbf{A}^{21} & \mathbf{A}^{22} & \cdots & \mathbf{A}^{2R} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{A}^{R1} & \mathbf{A}^{R2} & \cdots & \mathbf{A}^{RR} \end{pmatrix}, \mathbf{x} = \begin{pmatrix} \mathbf{x}^{1} \\ \mathbf{x}^{2} \\ \vdots \\ \mathbf{x}^{R} \end{pmatrix}, \ \mathbf{y} = \begin{pmatrix} \mathbf{F}^{11} + \cdots + \mathbf{F}^{1R} \\ \mathbf{F}^{21} + \cdots + \mathbf{F}^{2R} \\ \vdots \\ \mathbf{F}^{R1} + \cdots + \mathbf{F}^{RR} \end{pmatrix} \mathbf{i} + \begin{pmatrix} \mathbf{\Delta}^{1} \\ \mathbf{\Delta}^{2} \\ \vdots \\ \mathbf{\Delta}^{R} \end{pmatrix} + \begin{pmatrix} \mathbf{e}^{1} \\ \mathbf{e}^{2} \\ \vdots \\ \mathbf{e}^{R} \end{pmatrix} + \begin{pmatrix} \mathbf{e}^{pa1} \\ \mathbf{e}^{pa2} \\ \vdots \\ \mathbf{e}^{paR} \end{pmatrix}$$

where $\mathbf{A}^{rr}$ is the 17×17 matrix with intraregional input coefficients, with its typical elements computed as $a^{rr} = z_{ij}^{rr} / x_j^r$; $\mathbf{A}^{rs}$ is a 17×17 matrix with interregional import coefficients (with inputs from region r used per unit of output in region s, $r \neq s$), with its elements calculated as $a^{rs} = z_{ij}^{rs} / x_j^s$; $\mathbf{F}^{rr}$ and $\mathbf{F}^{rs}$ are the same 17×4 matrices defined previously, giving intraregional final demand and interregional imports for final demand, respectively; $\mathbf{\Delta}^r$ gives the 17-element vector of changes in inventories in region r; $\mathbf{e}^r$ is a 17-element vector with ordinary foreign exports in region r; and $\mathbf{e}^{par}$ is a 17-element vector with P&A exports of region r.

Solving equation (4-1) for $\mathbf{x}$ gives the following:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1} \mathbf{y} \qquad (4\text{-}2)$$

Let $\mathbf{v}$ denote the *NR*-element vector of value added, and let $\mathbf{c}$ denote the *NR*-vector of value-added coefficients, with its typical element calculated as $c_j^r = v_j^r / x_j^r$. The value-added equation then reads as follows:

$$\mathbf{v} = \hat{\mathbf{c}}\mathbf{x} = \hat{\mathbf{c}}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} = \hat{\mathbf{c}}\mathbf{L}\mathbf{y} \tag{4-3}$$

where $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is the interregional Leontief-inverse.

Value-added formation by sector and by region will be decomposed in two ways. First, we will consider total value added as a ratio of direct value added, both embodied in final demand of an industry (Oosterhaven, 1981). Second, the value added generated by foreign exports is decomposed into the direct effect, the intraregional indirect effect, and the interregional spillover effect.

For the first type of decomposition, the normalized income (or value added) multiplier will be used. It gives the total national income effects (i.e., $\mathbf{c}'\mathbf{L}\hat{\mathbf{y}}$) per unit of direct income incorporated in final demand (i.e., $\mathbf{c}'\hat{\mathbf{y}}$ and, taking the ratio, we have $\mathbf{c}'\mathbf{L}\hat{\mathbf{y}}(\hat{\mathbf{c}}\hat{\mathbf{y}})^{-1} = \mathbf{c}'\mathbf{L}(\hat{\mathbf{c}})^{-1}$). The national income multiplier for each region is normalized to obtain a key figure without a dimension. Furthermore, because we are primarily interested in the indirect effects, the direct income effect is subtracted from the total (i.e., we use $\mathbf{c}'\mathbf{L}(\hat{\mathbf{c}})^{-1} - \mathbf{i}'$).

The total national indirect value added induced by one unit of direct income in region r is denoted by $\mathbf{c}_n^r$ and is decomposed into within-region indirect income effects[12] and interregional income spillover effects

$$(\mathbf{c}_n^r)' = \sum_s (\mathbf{c}^s)'\mathbf{L}^{sr}(\hat{\mathbf{c}}^r)^{-1} - \mathbf{i}' \text{(total national indirect income effects)} \tag{4-4}$$

$$= (\mathbf{c}^r)'\mathbf{L}^{rr}(\hat{\mathbf{c}}^r)^{-1} - \mathbf{i}' \text{(within region indirect income effects)} \tag{4-4.1}$$

$$+\sum_{s \neq r} (\mathbf{c}^s)'\mathbf{L}^{sr}(\hat{\mathbf{c}}^r)^{-1} \text{ (interregional incomespillover effects)} \tag{4-4.2}$$

[12] The within-region indirect effects can be further decomposed into two effects, namely *intraregional effect without feedbacks* and *interregional feedbacks* (Oosterhaven, 1981; Zhang and Zhao, 2005; Miller and Blair, 2009). Though theoretically interesting, these feedback effects are relatively small, which is why they are not studied separately. Still, we should bear in mind that the intraregional indirect income effects in this study include interregional *feedbacks*. This also applies to formula (4-6.2), where interregional *feedbacks* are included in the intraregional indirect income effects.

This decomposition has been done for each of the eight regions, which enables us to make assessments, for example, for the impact of regional policy programs in certain regions (both on the nation as a whole and on the regions in question). In other words, this exercise helps usdetermine what would be the economy-wide indirect income effect if some investment (made in one specific region) generates a direct income effect of 1 billion RMB.

In this study, we are particularly interested in the actual income effects generated by foreign exports. As Table 4.2 shows, foreign exports are concentrated in China's coastal regions. From the viewpoint of production chains, the question is whether foreign exports spread their income-generating effects to interior regions through interregional income spillovers. If so, what is the magnitude? To answer these research questions, the income that is generated by ordinary foreign exports needs to be decomposed into direct income effect and indirect income effect (including intraregional indirect income effect and interregional spillovers). By formula, the value added generated (in region *r*) by ordinary foreign exports, which is generated both by its own foreign exports and by the foreign exports of the RoC, reads as follows:

$$\mathbf{v}_e^r = \hat{\mathbf{c}}^r \mathbf{L}^{rr} \mathbf{e}^r + \hat{\mathbf{c}}^r \sum_{s \neq r} \mathbf{L}^{rs} \mathbf{e}^s \qquad (4\text{-}5)$$

Now, formula (5) can be decomposed into the following effects (Oosterhaven, 1981; Miller and Blair, 2009), and this is done for each of the eight regions:

$$\mathbf{v}_e^r = \hat{\mathbf{c}}^r \mathbf{e}^r \quad \text{(within region direct income effects)} \qquad (4\text{-}6.1)$$

$$+ \;\; \hat{\mathbf{c}}^r (\mathbf{L}^{rr} - \mathbf{I}) \mathbf{e}^r \quad \text{(within region indirect income effects)} \qquad (4\text{-}6.2)$$

$$+ \;\; \hat{\mathbf{c}}^r \sum_{s \neq r} \mathbf{L}^{rs} \mathbf{e}^s \; \text{(interregional income spillover effects)} \qquad (4\text{-}6.3)$$

4.4 Decomposing the total income multipliers: Empirical results

Two types of empirical results will be presented in this section. First, we will discuss the decomposition of the national total indirect income effects using the normalized income multiplier (i.e., regardless of the type of final demand). This will shed light on each region's national total indirect income effect due to one unit of direct income impulse and is splitup into its own effect and its interregional spillovers. Second, given the significance of foreign exports, we will apply the IRIO methodology to decompose the total income generated by ordinary foreign exports into direct income, intraregional indirect income, and interregional income spillovers. Furthermore, net interregional income spillovers due to foreign exports are calculated, and we will link them to the position of China's regions in the global value chain.

Following Antràs et al.'s (2012) concept, the upstreamness, which reflects the average distance from final demand of interior regions, is expected to be larger, as these regions mainly supply natural resources and raw materials. Coastal regions, which are closer to the final consumers, will be positioned downstream in the production chains. We further expect that upstream regions are tied up firmly by interregional spillovers due to foreign exports of downstream regions.

4.4.1 Decomposing the normalized indirect income effects

Table 4.3 gives the average indirect income effects in which the average for each region is obtained by weighting the sectoral effects with sectoral total final demands.[13] The results show that the weighted averages of the total national indirect income effects have increased for all regions (row "Total"; for the definition of regions and their location, see Appendix 4.A).

In 2007, the largest total national indirect income effects are found in coastal regions, particularly in NC and EC (2.2 and 2.1, respectively). This means, for example, that one unit of direct income impulse in NC will lead to an economy-wide indirect income increase of 2.2 units. From 2002 to 2007, the largest change in the total national indirect income effect happened in SC (1.2 in 2002 vs. 1.8 in 2007). The next largest change took place in EC, with an increase from 1.6 in 2002 to 2.1 in 2007. It is clear that coastal regions are becoming more important in terms of total national indirect income generation.

[13] As shown in the derivation of formula (4-4), the normalization pertains to the income impulse incorporated in final demand, so weighting all sectoral effects by regional total final demand by industry gives a consistent average (Oosterhaven, 1981).

As mentioned previously, total national indirect income effects can be decomposed into intraregional indirect income effects and interregional income spillovers (formula (4-4)). From 2002 to 2007, six of the eight regions experienced an increase in intraregional indirect income effects (CR and SW are the exception), which is in line with the changes in aggregate intraregional input coefficients in Table 4.1. An increased aggregate intraregional input coefficient will lead to a larger multiplier. Policies that aim to maximize total national income growth would choose to stimulate income growth in NC and EC, as those regions generate not only large intraregional indirect income effects but also large interregional spillovers. For example, in 2007, one unit of income impulse in NC would generate 1.4 units of intraregional indirect income growth, associated with 0.7 unit income increase in RoC.

Table 4.3 Decomposition of economy-wide indirect income effects per unit of direct income: 2002 and 2007 (weighted averages)*

2007	NE	NM	NC	EC	SC	CR	NW	SW
Intra (1)	1.3	0.8	1.4	1.4	1.1	1.1	0.9	1.1
Inter (2)	0.4	0.9	0.7	0.8	0.7	0.5	0.6	0.6
Total (3)	1.7	1.7	2.2	2.1	1.8	1.7	1.6	1.7
Share (4)	23.7	54.5	34.5	35.6	39.5	32.5	41.8	32.8
2002								
Intra (1)	1.2	0.6	1.2	1.3	0.9	1.2	0.8	1.2
Inter (2)	0.2	0.8	0.5	0.3	0.3	0.3	0.6	0.3
Total (3)	1.5	1.4	1.8	1.6	1.2	1.5	1.4	1.5
Share (4)	16.0	56.5	30.1	17.9	21.7	20.2	40.6	19.4

* The "Intra" is intraregional indirect income effects using equation (4-4.1); "Inter" means interregional income spillovers using equation (4.2); "Total" is the sum of "Intra" and "Inter"; and "Share" is the ratio of interregional income spillovers to total national indirect income multiplier, i.e., row(4)=100*row(2)/row(3). The values of row (1) and row (2) are, respectively, averages of all sectoral intraregional indirect income effects and interregional income spillovers weighted by regional total final demand by industry. Results at industry level are available upon request.

Observe that the aggregate intraregional input coefficients are larger than the aggregate interregional import coefficients (see Table 4.1). Thus, the intraregional indirect income effects are expected to be bigger than interregional income spillovers. The results in Table 4.3 support this expectation, with the exception of NM, which has smaller intraregional income effects than interregional income spillovers. At the same time, interregional income spillovers increase in all regions, which is in line with the increase of aggregate interregional import coefficients from 2002 to 2007. More important, in most regions (except for NM) the growth in total national indirect income multipliers is primarily caused by a substantial increase in interregional income spillovers. This is clearly indicated by growing average ratios of interregional income spillovers to total national indirect income multipliers (the bottom row in each panel of Table 4.3).

Therefore, the conclusion is clear. By taking only the intraregional indirect income effects into account, we underestimate the economy-wide indirect income effects by one-quarter to one-half in 2007. Moreover, the interregional income spillovers are increasing in importance in total national indirect income effects over time. Thus, with regard to regional investment programs toward alleviation of income disparity, a thorough investigation of interregional income spillovers is necessary.

Table 4.4 presents the interregional income spillovers per unit of direct income. Column one shows the industry codes, and columns two through nine show region-specific total interregional income spillovers. The number 1.8 in row 3 and column NM is taken as an example to interpret the meaning of values. It indicates that one unit of extra direct income (or value added) in NM due to extra final demand for *food products* from NM induces an interregional spillover on value added in the RoC that is 1.8 in 2007.

First, it is observed that, in almost all cases, the average interregional income spillovers are becoming larger but remain smaller than one. Of note, the values of interregional income spillovers experienced a *convergence* from 2002 to 2007 (as measured by the *standard deviation*, 0.20 in 2002 vs. 0.16 in 2007). Notably, relatively small interregional income spillovers from EC and SC showed the largest increase within these five years (from 0.3 and 0.3 in 2002 to 0.8 and 0.7 in 2007, respectively). NM is extremely strong in both years. These findings are in line with those displayed in Table 4.1. The interregional deliveries increased substantially in EC and SC, while they remained high in NM (see Table 4.1).

Table 4.4 Interregional income spillover effects per unit of direct income*

2007 Industry	NE	NM	NC	EC	SC	CR	NW	SW
1	0.1	0.6	0.2	0.2	0.1	0.1	0.2	0.1
2	0.1	0.3	0.5	0.5	0.2	0.4	0.2	0.4
3	0.3	1.8	1.1	0.7	0.8	0.5	0.6	0.2
4	0.7	1.6	1.2	1.0	0.8	0.8	0.9	0.8
5	0.3	2.4	0.7	1.2	0.8	0.5	0.7	0.7
6	0.5	1.3	1.0	0.7	0.8	0.6	0.8	0.6
7	0.4	1.1	1.1	1.1	1.2	0.9	0.8	0.7
8	0.4	1.7	0.8	0.9	0.5	0.6	0.5	0.7
9	0.7	1.7	1.6	1.3	1.3	1.0	0.6	0.7
10	0.8	1.1	1.1	0.8	0.7	0.9	1.2	0.9
11	0.5	2.0	0.9	1.0	1.4	1.3	2.0	1.4
12	0.9	1.3	1.4	0.8	1.2	0.9	1.4	0.7
13	0.1	0.4	0.4	0.3	0.6	0.4	0.4	0.2
14	0.6	0.9	1.0	1.3	0.3	0.6	0.3	0.5
15	0.7	1.9	0.8	1.2	0.7	0.8	1.3	1.1
16	0.1	0.4	0.3	0.2	0.1	0.2	0.2	0.3
17	0.1	0.3	0.2	0.2	0.1	0.2	0.2	0.2
Average	**0.4**	**0.9**	**0.7**	**0.8**	**0.7**	**0.5**	**0.6**	**0.6**
2002								
1	0.1	0.7	0.2	0.1	0.1	0.1	0.2	0.1
2	0.0	0.2	0.2	0.1	0.1	0.1	0.2	0.1
3	0.4	1.1	0.3	0.3	0.2	0.3	0.8	0.1
4	0.3	1.2	0.5	0.4	0.3	0.4	0.9	0.4
5	0.2	2.8	0.8	0.6	0.2	0.4	1.3	0.5
6	0.2	0.8	0.4	0.3	0.4	0.3	0.7	0.4
7	0.4	1.3	0.7	0.5	0.3	0.6	0.8	0.4
8	2.3	1.0	0.5	0.3	0.2	0.2	0.6	0.3
9	0.2	1.9	0.9	0.6	0.4	0.4	0.7	0.5
10	0.2	1.3	0.7	0.4	0.3	0.5	1.1	0.5
11	0.5	1.4	0.9	0.3	0.6	0.6	0.6	0.4
12	0.3	0.9	1.2	0.4	0.4	0.6	1.2	0.5
13	0.1	0.5	0.2	0.2	0.2	0.2	0.3	0.2
14	0.1	0.4	0.3	0.2	0.3	0.1	0.2	0.1
15	0.4	1.6	1.0	0.5	0.4	0.6	1.1	0.6
16	0.1	0.4	0.3	0.1	0.1	0.2	0.3	0.2
17	0.1	0.4	0.2	0.1	0.1	0.1	0.2	0.2
Average	**0.2**	**0.8**	**0.5**	**0.3**	**0.3**	**0.3**	**0.6**	**0.3**

* See Appendix 4.B for the meaning of the industry numbers. The subtotals of interregional income spillovers to the other seven regions are computed using equation (4-4.2). The average for all industries is the average of all sectoral spillovers weighted by regional total final demand by industry. They are the same as those reported in rows (2) in Table 4.3.

To further explain these tremendous increases in the averages, it is helpful to check the results at the industry level. Increased interregional income spillovers for large sectors (in terms of relative size in final demand, which is used as weights in determining the averages) are observed in these regions, for example, from 0.4 in 2002 to 1.2 in 2007 for *electronic products* (industry 12) in SC.

Second, income impulses to NM would generate a relatively larger impact in the RoC. When carefully checking the interregional income spillovers at the industry level, in 2007, four industries show strikingly large values in NM: *food products* (industry 3 with 1.8), *wooden products* (industry 5 with 2.4), *transport equipment* (industry 11 with 2.0), and *construction* (industry 15 with 1.9). Still, this can be explained by the aggregate input structures of these industries (see Appendix 4.C). Specifically, these industries have relatively high aggregate interregional import coefficients, combined with low aggregate intraregional input coefficients and low aggregate value-added coefficients.

Third, in comparing 2007 with 2002, several big changes are worth exploring. The sharp increase of interregional income spillovers in industry 11 in NW (from 0.6 in 2002 to 2.0 in 2007) is primarily caused by the dramatic decrease in the aggregate value-added coefficient (25 percentage points) plus a modest increase in the aggregate interregional import coefficient (8 percentage points).[14] The next largest increase is in *electricity, gas, and water supply* (industry 14) in EC (from 0.2 in 2002 to 1.3 in 2007), which can be explained mostly by the large contraction in aggregate value-added coefficients (25 percentage points) associated with a big increase in the aggregate interregional import coefficients (12 percentage points). A similar explanation holds for the big change in industry 11 in SW. In contrast, large aggregate interregional import coefficient increases are responsible for the big increases in SC for *chemical products* (industry 7, from 0.3 in 2002 to 1.2 in 2007) and *metal*

[14] According to the results, the largest change happened in *non-metallic mineral products* (industry 8 in NE decreased from 2.3 in 2002 to 0.4 in 2007). This change is primarily caused by an extreme increase in aggregate value-added coefficient in NE (increased from merely 6% in 2002 to 26% in 2007). The original data show that the operating surplus of industry 8 in NE in 2002 is negative (i.e., -19.5 billion RMB), which means that the entire industry ran a great deficit. Many heavy industry firms were on the verge of bankruptcy in NE by then. Because of the "*Northeast Revitalization Program*" launched in 2003, those heavy industries in NE were greatly supported. This investment program, associated with a huge number of layoffs (as is observed from the decrease of total wages paid to workers, 14.0 billion RMB in 2002 vs. 8.7 billion RMB in 2007), contributed to a positive operating surplus in 2007 (i.e., 17.7 billion RMB) and, therefore, the extreme increase in the aggregate value-added coefficient. See Appendix 4.C for detailed results of the aggregate input structures by industry by region.

products (industry 9, from 0.4 in 2002 to 1.3 in 2007). Clearly, interregional trade becomes more important within China (see the panel termed "RoC" in Appendix 4.C).

This empirical analysis gives a general picture on what would be the total national indirect income effects (as well as its two components: intraregional indirect income effects and interregional income spillovers) if one unit of direct income impulse were generated in a particular region. It provides a tool for assessing certain regional policy programs, both to the region in question and to the nation as a whole.

4.4.2 Decomposition of total income effects due to foreign exports

At the same time, because of the increasing importance of interregional interdependencies among China's regions, we are interested in the income effects generated by actual final demand (e.g., foreign exports), both for the specific region and for the RoC. So we will use the IRIO model to a specific application (i.e., decomposition of total income effects induced by foreign exports). It may help determine which regions locate more upstream (i.e., with net *inflowing* interregional income spillovers) or downstream (i.e., with net *outflowing* interregional income spillovers) in production chains.

Next, we will investigate the regional value-added generation due to foreign exports.[15] Previous studies included P&A exports in their analysis, partly because of the non-availability of data (Yang and Lahr, 2008; He and Duchin, 2009). However, Jarreau and Poncet (2012) argue that the P&A exports should be distinguished to measure the true contribution of foreign exports to economic growth (Pei et al., 2012). This also holds true in our study, as we are interested in the value added generated by ordinary foreign exports.

[15] One of the reasons for this specific investigation is that the ability to export abroad is argued to indicate relatively high productivity due to the competition on foreign markets, the technologically advanced products demanded there, the technology transferred with foreign investments, and so forth (Melitz and Trefler, 2012).

Table 4.5 Regional values added due to foreign exports: 2002 and 2007*

2007	VA due to foreign exports	% of total VA	Direct (% VA)	Own Indirect (% VA)	NE	NM	NC	EC	SC	CR	NW	SW
					Interregional income spillovers *from* foreign exports in (% VA):							
NE	384	17	25	33	-	5.3	5.5	14.2	11.7	2.1	1.7	0.9
NM	389	28	48	33	1.3	-	6.2	6.3	3.6	0.8	1.1	0.3
NC	642	17	30	40	1.6	7.9	-	9.8	6.2	2.0	2.0	0.4
EC	1734	32	37	55	0.2	0.7	0.7	-	4.6	0.8	0.4	0.2
SC	1088	28	43	45	0.6	1.3	1.1	6.0	-	0.8	0.8	0.8
CR	517	10	17	20	1.1	3.0	6.8	33.5	15.4	-	2.1	0.8
NW	414	22	30	25	1.8	3.3	5.3	19.1	12.0	2.4	-	1.2
SW	231	9	21	26	1.3	2.0	3.9	17.1	23.6	1.9	2.9	-
2002												
NE	119	10	39	43	-	5.3	3.5	3.2	4.1	0.6	0.8	0.5
NM	90	14	54	36	0.8	-	3.4	1.8	2.8	0.2	0.2	0.2
NC	172	10	35	47	0.9	7.7	-	4.5	3.2	0.9	0.7	0.2
EC	577	24	39	54	0.2	0.8	1.0	-	3.5	0.8	0.2	0.2
SC	521	28	50	44	0.3	0.8	0.6	3.0	-	0.4	0.3	0.5
CR	145	6	22	30	1.4	4.6	6.8	19.9	13.3	-	1.4	0.9
NW	46	6	31	31	2.9	4.3	4.8	13.9	8.2	2.4	-	1.3
SW	77	6	27	38	1.6	2.5	2.7	7.7	17.8	1.2	2.1	-

* Value added is in billion RMB (current price), which is embodied in foreign exports. The effects, including the direct effect (formula 4-6.1), the indirect effect (formula 4-6.2), and seven interregional spillovers *from* foreign exports production in other regions (formula 4-6.3), are percentage contributions that add to 100%.

Table 4.5 presents the results for the value-added generation due to foreign exports: columns two and three give the total value added generated by China's foreign exports, both in absolute and in percentage terms.[16] The 384 billion RMB for Northeast (NE) is the total value added generated by China's foreign exports (i.e., own foreign exports in NE and those in the RoC). The figure 17% indicates that 17% of NE's total GDP can be attributed to China's foreign exports. For the 384 billion RMB value added in NE generated by China's foreign exports, 25% of it is directly generated by its own foreign exports and 33% is indirectly generated by its own foreign exports.

Three groups of regions may be distinguished in 2007. At the high end, the East Coast (EC), Northern Municipalities (NM), and South Coast (SC) have, respectively, 32%, 28%, and 28% of their regional GDP generated by China's foreign exports. Medium ones are Northwest (NW), NE, and North Coast (NC) with 22%, 17%, and 17% of their regional GDP formation by China's foreign exports. Low ones include Central Regions (CR) and Southwest (SW), with only 10% and 9% of their regional GDP generated by China's foreign exports.

The following columns show the decomposition of value added generated by foreign exports according to formula (4-6)—namely, the direct effect, the own indirect effect, and the interregional spillovers. The column with direct effects has the same three groups as in the share of value added generated by foreign exports to total value added. However, in the column with own indirect effect, EC, SC, and NC are relatively large, while SW, NW, and CR are relatively small. Note that these indirect effects are approximately positively correlated to the multipliers as reported in Table 4.3 (see row "Intra"). The difference is that we use foreign exports weights here instead of total final demand weights.

[16] The detailed results at industry level are omitted because of space constraints but are available on request.

Table 4.6 Net interregional income spillovers to each region due to foreign exports: 2002 and 2007*

		Foreign exports-led net interregional income spillovers *to* (billion RMB)							
2007	Local value added generation by own foreign exports (billion RMB)	EC	SC	NM	NC	NE	SW	NW	CR	**Total**
EC	1,595	-	-14.9	13.2	50.2	50.5	36.5	72.6	160.2	**368.2**
SC	957	14.9	-	-0.1	27.6	38.4	45.5	40.5	71.3	**238.0**
NM	315	-13.2	0.1	-	26.4	15.1	3.6	9.5	12.3	**53.7**
NC	449	-50.2	-27.6	-26.4	-	10.8	6.2	9.0	22.7	**-55.5**
NE	223	-50.5	-38.4	-15.1	-10.8	-	-0.4	0.8	-2.3	**-116.5**
SW	109	-36.5	-45.5	-3.6	-6.2	0.4	-	-1.5	-0.2	**-93.0**
NW	228	-72.6	-40.5	-9.5	-9.0	-0.8	1.5	-	0.9	**-130.0**
CR	191	-160.2	-71.3	-12.3	-22.7	2.3	0.2	-0.9	-	**-264.9**
2002										
EC	537	-	-4.5	-3.1	2.2	2.6	4.7	5.0	24.0	**30.9**
SC	490	4.5	-	-1.4	2.3	3.2	11.3	2.3	16.9	**39.2**
NM	81	3.1	1.4	-	10.2	5.5	1.8	1.8	6.4	**30.2**
NC	141	-2.2	-2.3	-10.2	-	2.6	1.7	1.1	8.3	**-1.1**
NE	98	-2.6	-3.2	-5.5	-2.6	-	0.6	0.4	1.2	**-11.7**
SW	50	-4.7	-11.3	-1.8	-1.7	-0.6	-	-1.0	0.4	**-20.7**
NW	29	-5.0	-2.3	-1.8	-1.1	-0.4	1.0	-	0.9	**-8.7**
CR	75	-24.0	-16.9	-6.4	-8.3	-1.2	-0.4	-0.9	-	**-58.1**

* All figures in the Table are absolute values (billion RMB, current prices). A positive entry indicates net interregional income spillovers from the region in a column to the region in a row; negative entries indicate the opposite.

Next, we investigate the interregional income spillovers due to foreign exports. The foreign exports from EC and SC benefit the regions CR, NW, and SW indirectly to a considerable extent. In percentages, for example, the interregional income spillovers to CR from foreign exports in EC and SC, respectively, represent 33.5% and 15.4% of the total value added generated in CR by China’s foreign exports. In other words, when the global financial crisis hit EC and SC, their foreign export growth decreased while the income growth in CR contracted.

To provide another perspective, we will also investigate the interregional income spillovers due to foreign exports from a sending (vs. receiving) and a net (vs. gross) viewpoint. The second column in Table 4.6 gives the total of the direct and indirect own income due to their own foreign exports in each region (i.e., the column “Direct” plus the column “Own Indirect” from Table 4.5, multiplied by the corresponding values of column “VA”). Two coastal regions are outstanding—namely, EC and SC, which (directly and indirectly) realized 1,595 billion RMB and 957 billion RMB income, respectively, due to their own foreign exports in 2007. The size difference of foreign exports is obvious for different regions (recall the regional shares in foreign exports in Table 4.2, in which EC and SC take more than two-thirds of total foreign exports in 2007) and also partly drives our estimation of interregional income spillovers due to foreign exports.

Not surprisingly, the foreign exports executed in regions EC and SC have strong interregional income spillovers to the RoC. Imagine the production chain (or the global value chain; Antràs et al., 2012). The downstream regions are closer to final consumers in the RoW, while upstream ones provide raw material or natural resources residing at the other end in the production chain. Viewed in this way, the region’s position in the production chain can be traced by using the absolute interregional income spillovers due to foreign exports because they indicate the actual direct and indirect strengths of the supply chain. Given that interregional income spillovers are two-way, the *net* interregional income spillovers at the bilateral (or bi-regional) level are defined as the sum of each region’s *outflowing* interregional income spillovers less its *inflowing* ones.

The foreign exports of EC and SC are extremely beneficial to the value-added formation in the RoC. Partly because of the locational advantage of EC and SC, the RoC realized net *inflowing* interregional income spillovers of 368 billion RMB from

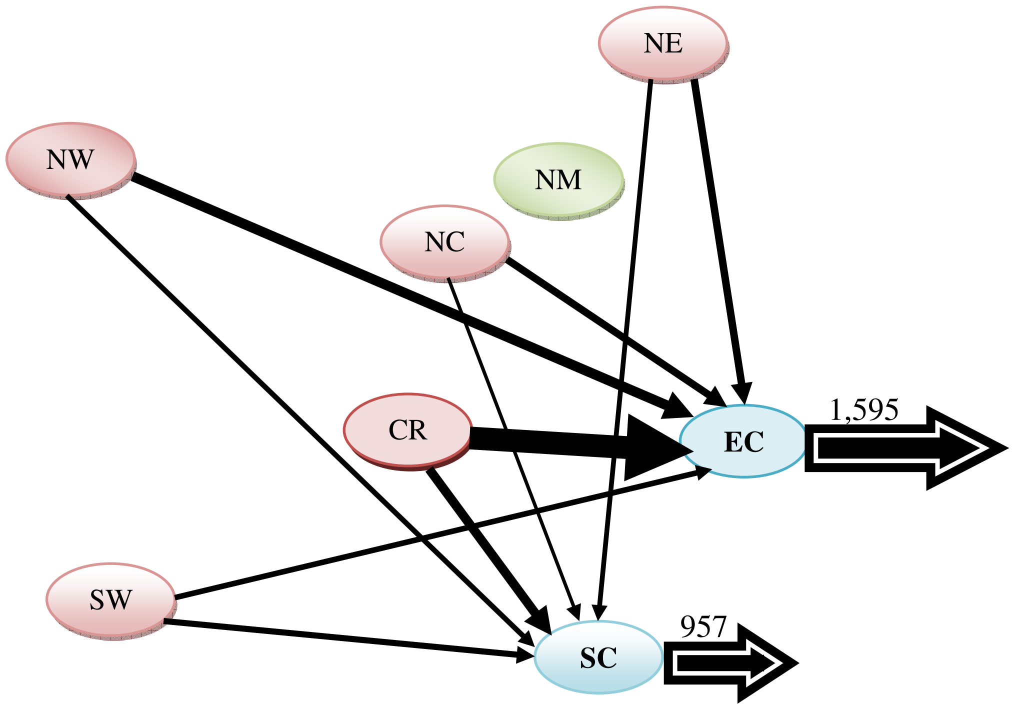
EC and 238 billion RMB from SC in 2007. CR benefits mainly from EC and SC, running a 265 billion RMB negative net interregional income spillover (i.e., more *inflowing* interregional income spillovers than *outflowing* ones). Thus, it is evident that, within China, SC and EC are the downstream regions in the production chain in terms of net interregional income spillovers to other regions. In contrast, CR and NW, among others, are the upstream regions.

Moreover, the net interregional income spillovers from foreign exports in EC and SC have contributed to growth in other regions (NM even changed from being a net *outflowing* region to EC in 2002 to being a net *inflowing* one from EC in 2007). That is, income formation in upstream regions relies more on foreign exports in downstream regions over time. The largest absolute change (in terms of net *inflowing* income spillovers) occurs for CR, from -58.1 billion RMB in 2002 to -264.9 billion RMB in 2007. In addition, at least a threefold growth occurs in other upstream regions, which indicates the pronounced upstream nature of these regions. Thus, instead of convergence for interregional income spillovers among regions, divergence is observed. In other words, the regions' positions in the production chain have become even more pronounced.

Figure 4.3 visualizes the net interregional income spillovers due to foreign exports. The thickness of the arrows indicates the size of net value-added formation due to foreign exports in the sourcing region (that is pointed by the arrow), with a threshold of 38 billion RMB in absolute values. The two largest values for EC and SC in 2007 (see column two in Table 4.6) are own value added (directly and indirectly) generated by their own foreign exports. One relatively isolated foreign exporting region—namely, NM—experienced neither large *outflowing* interregional income spillovers to the RoC nor significant *inflowing* ones from the RoC. This exception may be partly due to its unique characteristic of containing China's capital city.

When inspecting the dynamics, it is evident that the two (i.e., EC and SC) dominant foreign exports centers, in terms of positive net interregional income spillovers, strongly increased in importance. The net interregional income spillovers were quite small for these two downstream regions in 2002, roughly 30.9 billion RMB in EC and 39.2 billion RMB in SC. These values increased to 368.2 billion RMB in EC and 238.0 billion RMB in SC in 2007, respectively.

Figure 4.3 Net interregional income spillovers due to foreign exports, 2007*



* The arrows point to the origin of the net interregional income spillovers; the thickness of the arrows indicates the size of each net interregional income spillover (with a threshold of 38 billion RMB in absolute values). Please refer to Table 6 for more detailed figures. The two values—namely, 1,595 billion RMB for EC and 957 billion RMB for SC—are own (direct and indirect) value added generated by their own foreign exports.

This finding is comparable to the study of Bems et al. (2010), who report that 20%–30% of the decline of the United States' and European Union's final demand was borne by foreign countries through demand spillovers, with member countries of the North American Free Trade Agreement and emerging Europe hit the hardest. Similar reasoning can be applied to China (i.e., if the foreign exports were contracting in EC and SC, interior regions would have been hit severely).

4.5 Conclusion and discussion

By using China's modified 2002 and 2007 interregional input-output tables, we explored two distinct but inherently related empirical questions. This novel dataset, which separates processing and assembling exports from ordinary exports, enables us to evaluate a hypothetical policy program and account for actual income formation due to ordinary foreign exports.

In terms of total national indirect income multipliers, coastal regions have relatively larger effects than interior regions. This also holds true for interregional income spillovers in 2007. Moreover, interregional income spillovers account for one-quarter (for Northeast) to one-half (for Northern Municipalities) of total national indirect income multipliers in 2007, which is clearly not negligible when evaluating regional policy programs.

Given the relatively larger income multipliers in coastal regions, one policy implication is worth noting. All other things being constant, income impulses in coastal regions would generate a larger total national income. At the same time, we find that the intraregional indirect income effects dominate the total income multiplier. In this regard, to achieve growth in interior regions, more investment in interior regions would be preferred (see also He and Duchin, 2009).

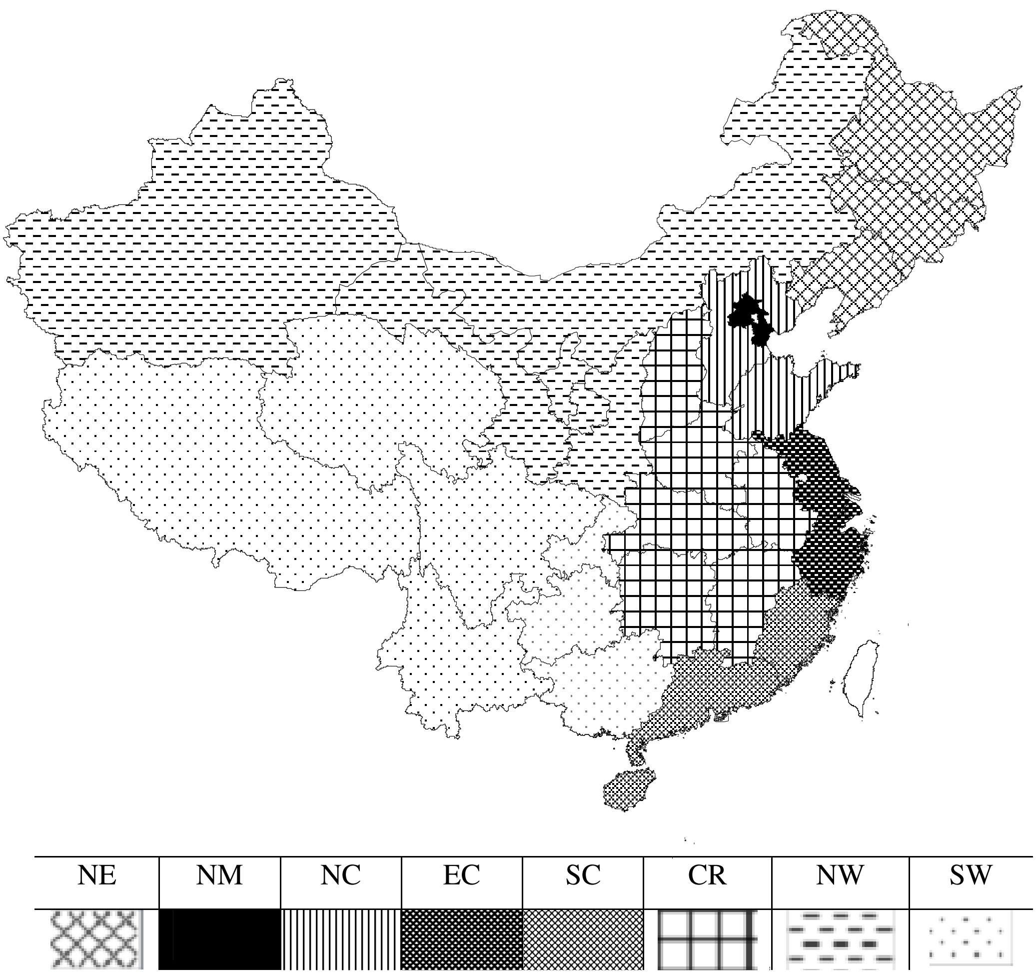
In addition, net interregional income spillovers are computed to position China's individual region (either upstream or downstream) in the production chain. China's regions show clear upstream and downstream features. In terms of interregional income spillovers due to foreign exports, three interior regions (Central Regions, Northwest, and Southwest) occupy the upstream ends, providing natural resources and raw materials, which are relatively far from final users. In contrast, the East Coast and South Coast are downstream regions with net interregional income spillovers to interior regions. Importantly, these positions in the production chain become more pronounced over time, which may have implications for the income per capita differences among regions.

It is also found that China is integrated firmly through foreign exports in coastal regions, which have absolutely strong interregional income spillovers to interior regions. In this sense, despite the conventional interpretation of the importance of foreign exports, it has an additional role to play; that is, to link China's different regions together through interregional income spillovers.

Appendix

4.A Classification of China's eight regions

Code	Region	Provinces included
NE	Northeast	Heilongjiang, Jilin, Liaoning
NM	Northern Municipalities	Beijing and Tianjin
NC	North Coast	Hebei and Shandong
EC	East Coast	Shanghai, Jiangsu, Zhejiang
SC	South Coast	Guangdong, Fujian, Hainan
CR	Central Regions	Shanxi, Henan, Hubei, Hunan, Anhui, Jiangxi
NW	Northwest	Inner Mongolia, Shannxi, Ningxia, Gansu, Xinjiang
SW	Southwest	Sichuan, Chongqing, Yunnan, Guizhou, Guangxi, Qinghai, Tibet



4.B Sector classification of China’s interregional input-output tables

Industry	Description
1	Agriculture
2	Mining
3	Food products
4	Textile and wearing apparel
5	Wooden products
6	Paper and printing
7	Chemical products
8	Non-metallic mineral products
9	Metal products
10	Machinery
11	Transport equipment
12	Electronic products
13	Other manufacturing products
14	Electricity, gas and water supply
15	Construction
16	Trade and transport
17	Services

4.C Aggregate sectoral input coefficients (in %) per region, 2007*

Intra	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
NE	42	29	69	51	63	50	50	62	56	54	65	52	24	65	62	40	38
NM	32	27	37	29	31	36	37	37	41	39	51	34	28	62	39	40	37
NC	35	49	66	69	52	68	61	55	59	62	54	69	49	51	60	42	34
EC	32	49	53	68	57	62	54	55	52	60	63	52	41	54	59	39	41
SC	29	28	59	56	58	52	41	58	43	47	48	44	40	59	63	30	34
CR	35	46	65	65	62	57	46	60	52	48	49	46	48	54	61	34	36
NW	32	26	50	53	47	43	61	45	51	38	41	28	29	55	44	32	27
SW	34	40	58	59	51	49	51	53	55	48	63	51	30	59	57	35	34
RoC																	
NE	3	4	3	16	4	12	6	6	11	15	5	15	5	8	13	3	5
NM	21	14	29	36	34	26	19	32	25	24	21	18	14	11	36	11	10
NC	8	10	10	10	12	8	12	14	17	13	16	9	7	19	11	10	9
EC	7	10	12	8	14	7	11	15	17	10	9	8	7	19	17	4	4
SC	6	9	12	13	10	12	20	8	21	16	21	15	15	5	10	6	5
CR	6	11	7	10	7	10	18	10	16	21	24	20	10	12	12	10	8
NW	9	10	13	17	16	19	10	14	12	29	32	33	16	7	29	11	11
SW	3	13	4	14	15	15	13	15	11	21	14	14	10	8	18	11	9
RoW																	
NE	2	4	7	7	9	11	22	5	12	9	7	14	7	4	4	2	4
NM	4	5	16	12	20	16	25	11	16	12	14	34	17	3	6	5	6
NC	1	3	6	3	7	4	8	3	8	4	4	5	3	4	1	2	2
EC	1	6	8	5	11	9	18	6	14	8	9	23	9	5	4	3	3
SC	1	6	7	7	10	12	20	5	18	11	12	27	17	4	2	2	2
CR	1	3	3	3	3	5	12	2	9	6	7	8	3	2	2	2	2
NW	2	3	7	7	11	10	10	4	8	10	11	20	15	2	4	3	4
SW	1	4	3	4	8	8	11	4	10	7	7	11	8	2	3	2	3
VAC																	
NE	54	63	21	26	24	27	22	26	21	23	22	19	64	23	22	55	53
NM	43	55	19	23	15	22	20	20	18	25	14	14	41	24	19	44	47
NC	55	37	18	18	29	20	19	28	16	21	26	16	41	26	27	46	55
EC	60	34	26	19	18	23	17	24	18	22	19	17	44	23	20	54	52
SC	63	56	23	25	22	24	19	29	19	26	19	15	28	32	24	61	58
CR	59	40	25	22	27	28	24	28	23	25	20	26	39	32	26	54	54
NW	57	61	30	23	26	28	19	36	29	23	17	20	40	36	23	54	58
SW	57	61	30	23	26	28	19	36	29	23	17	20	40	36	23	54	58

* Intra means aggregate intraregional input coefficients (in %); RoC means aggregate interregional import coefficients from the Rest of China (in %); RoW gives the aggregate foreign import coefficients (in %); and VAC means the aggregate value-added coefficients (in %).

4.C Aggregate sectoral input coefficients (in %) per region, 2002 (continued)

Intra	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
NE	39	24	59	53	56	50	57	78	64	62	52	54	34	38	65	40	43
NM	33	19	34	35	37	26	39	33	47	33	41	39	28	25	35	35	36
NC	35	42	58	59	53	53	57	49	55	52	57	60	41	36	64	42	32
EC	41	34	60	64	65	56	53	55	60	59	57	49	49	42	64	40	41
SC	35	33	56	49	46	38	39	47	44	42	47	37	40	48	54	37	39
CR	35	36	65	64	64	54	54	56	59	54	56	51	51	42	64	43	38
NW	35	29	57	46	42	41	60	42	48	44	31	43	32	42	45	40	31
SW	33	42	53	61	62	50	60	55	63	60	66	60	43	38	67	36	40
RoC																	
NE	4	1	8	7	4	6	7	11	2	3	13	7	3	3	7	3	3
NM	21	11	27	24	35	26	24	27	23	31	21	12	17	17	35	10	13
NC	6	7	6	7	16	8	13	13	17	14	15	17	7	10	13	9	8
EC	3	2	5	5	6	4	7	5	7	5	4	6	4	7	6	1	1
SC	3	2	4	6	4	13	5	5	7	6	11	9	5	7	7	3	3
CR	5	5	5	7	7	8	15	5	8	12	13	18	7	3	10	6	5
NW	8	10	15	22	28	21	14	19	16	25	24	30	15	5	24	11	10
SW	3	5	4	10	10	12	8	7	7	10	6	9	6	5	9	8	5
RoW																	
NE	1	2	4	12	5	5	10	4	5	5	7	12	2	1	3	2	3
NM	4	8	8	16	13	10	14	7	12	9	17	30	11	3	5	12	2
NC	1	3	4	7	3	3	4	2	3	3	3	4	2	2	2	2	3
EC	3	7	8	9	12	12	18	12	14	12	15	23	9	3	8	6	3
SC	3	10	11	21	16	16	34	13	27	23	18	33	23	11	15	4	4
CR	0	1	1	2	1	1	1	1	4	2	2	1	1	0	1	1	2
NW	1	2	3	3	4	3	3	2	6	3	3	2	1	1	4	1	2
SW	0	2	1	1	1	1	2	1	3	2	1	3	1	0	1	1	2
VAC																	
NE	56	73	28	29	34	39	26	6	29	30	27	28	61	58	25	54	51
NM	42	62	30	25	15	38	23	33	18	27	21	19	43	55	25	43	49
NC	58	47	33	27	28	36	27	36	25	30	25	19	49	52	21	46	57
EC	53	57	27	23	18	28	22	28	19	24	24	22	38	48	21	52	55
SC	59	54	29	24	33	33	22	35	21	29	24	21	33	34	23	56	54
CR	60	58	29	28	28	37	29	38	29	33	29	29	41	54	25	51	55
NW	57	60	26	30	25	36	24	37	30	28	41	25	52	52	27	48	58
SW	57	60	26	30	25	36	24	37	30	28	41	25	52	52	27	48	58

Chapter 5

TRADE, PRODUCTION FRAGMENTATION, AND CHINA'S CARBON DIOXIDE EMISSIONS[1]

5.1 Introduction

When calculating a country's emissions, a key issue that has received increased attention is whether to use production-based or consumption-based accounting principles. Production-based emission accounting measures all emissions generated by the production activities of a country. Consumption-based emission accounting measures all emissions that are necessary worldwide to satisfy the needs of consumers of a country (where consumption includes private and government consumption and investments).[2] The difference between these two accounting methods is given by the trade in emissions (Serrano and Dietzenbacher, 2010). Adopting the consumption-based approach, input-output (IO) techniques have contributed to more accurate estimates of pollution, in particular the emissions embodied in trade flows.[3] The issue is also relevant for policy debates, as witnessed by the question on whether China should be held accountable for all of its emissions. Weber et al. (2008), for example, have estimated that roughly one third of China's carbon dioxide (CO_2) emissions were due to exports and thus 'on behalf of foreign consumers'. An aspect that has not received much attention in this discussion is the distinction between different types of trade flows. This chapter will distinguish between production for domestic purposes and production for two types of exports.

Production processes have become more and more internationally fragmented. This implies an increase in the outsourcing (and offshoring) of production activities to

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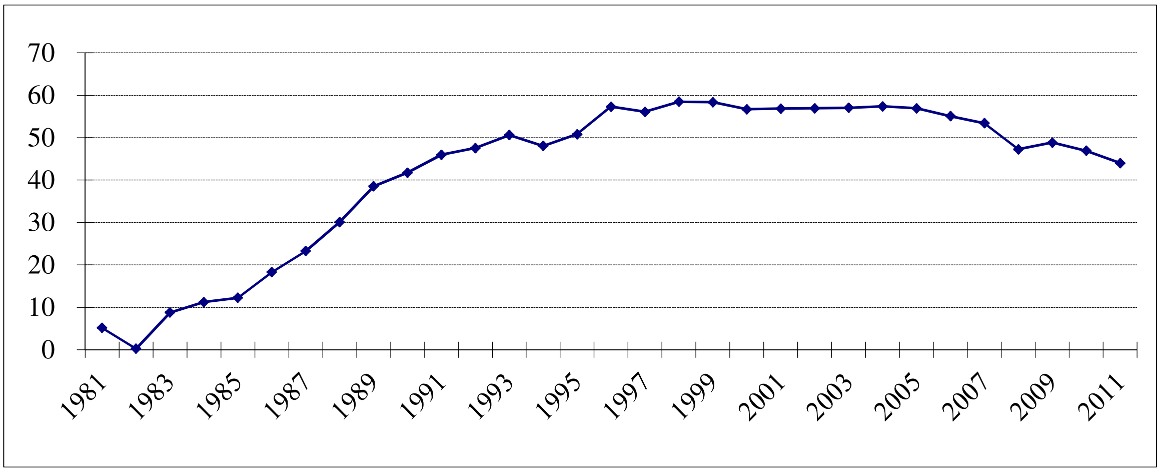
[1] This chapter was originally published in *Journal of Environmental Economics and Management*, vol. 64, pp. 88-101, 2012 (jointly written with Erik Dietzenbacher and Cuihong Yang).

[2] See, for example, Gallego and Lenzen (2005), Rodrigues et al. (2006), Lenzen et al. (2007), and Peters (2008) for recent contributions.

[3] See, for example, Forssell (1998), Forssell and Polenske (1998), Suh and Kagawa (2005), Turner et al. (2007), Wiedmann et al. (2007), and Suh (2009) for overviews of applying IO to environmental issues. Copeland and Taylor (2004) provides an excellent survey of the literature on trade and the environment.

other countries, which has both economic and environmental effects (see Dean and Lovely, 2010, for a recent contribution). China is a major player in this international production fragmentation. Huge amounts of processing trade take place where a large share of the raw and auxiliary materials, parts and components, accessories, and packaging materials are imported from abroad free of duty. The finished products are re-exported after they have been processed or assembled by enterprises. For example, Figure 5.1 shows that processing exports accounted for more than 50% of China's annual total exports in the period 1996-2007 (although it is expected to decline slowly because outsourcing to China is becoming less attractive - partly due to rising costs - which will lead to a hump-shaped curve).

Figure 5.1 China's processing exports as percentage of the total exports*



* The data for 1981-2008 are from NBS (2009), those for 2009-2010 are from NBS (2011), and those for 2011 are from a report by China Customs.

In this study, we focus on China's exports. Because processing exports typically involve the input of labor (e.g., for assembly) and few Chinese intermediate inputs, the Chinese part of the production chain of these goods is relatively short. Also relatively little CO_2 will be emitted in China. As a consequence, when calculating the Chinese emissions involved in China's exports, it is important to make a distinction between processing exports and non-processing exports. One of our major findings is that Chinese CO_2 emissions necessary for the country's exports are overestimated by more than 60% if the distinction between processing and non-processing exports is not taken into account (as was the case in Weber et al., 2008).

For our analysis we use an IO framework. The IO framework is useful for ascribing certain effects (e.g., emissions) to actions that have taken place (e.g., exports or private consumption). It includes the technical relationships between industries involved in the production process. Ascribing part of the actual emissions to, for example, exports does not require the modeling and simulation of economic behavior (for which the CGE approach is more appropriate). Also, a major advantage is that many national IO tables are now available at a detailed level and are complemented by environmental and other data at the same level (see Miller and Blair, 2009, for an introduction to IO analysis).

Recently, a special, tripartite IO table has been developed for China (see Lau et al., 2006, 2007 for details on the table construction). The table distinguishes between the following three categories: production for domestic purposes only; production of processing exports; and other production (which includes production of non-processing exports and production of foreign-invested enterprises for domestic purposes).[4] Its compilation was possible because processing imports can - according to the official regulations - only be used to produce goods for processing exports, but not for other purposes (such as domestic sales). The consequence is that the customs and tax authorities have collected much of the underlying information needed for this tripartite IO table.

Processing exports generate value added in China. However, the same amount of non-processing exports or domestic consumption induces much more value added. This is because non-processing exports and domestic consumption require more domestic inputs than processing exports (which rely almost entirely on processing imports). Using the tripartite IO table - which also includes information on value added - Lau et al. (2006, 2007) report that the total domestic value added generated by 1000 Remminbi (RMB) of processing exports is 287 RMB, whereas it is 633 RMB for non-processing exports.[5] This implies that processing exports contribute less to

[4] In a similar vein, Koopman et al. (2008), Chen et al. (2009) and Dean et al. (2011) split the ordinary IO table into two parts with a different production structure. The way they treat processing exports is more or less the same as was done in the table used in this study. The difference is that they (implicitly) assume the same production structure for non-processing exports and domestic production. This overlooks the differences between foreign-invested enterprises and domestic firms, and seems less plausible than the assumptions used in Lau et al. (2006, 2007).

[5] Production fragmentation and its impact on value added generation have received ample attention in the recent literature. For example, see Feenstra et al. (1999), Fung and Lau (2001), Feenstra and Hanson (2004), Fung et al. (2006), and Ferrantino and Wang (2008) for the necessary adjustments in

value added and emissions than the same amount of non-processing exports. However, when compared to non-processing exports, the reduction in emissions is larger than the reduction in value added. That is, processing exports have a lower emissions-value added ratio (see Muller et al., 2011, for a related computation) than non-processing exports.

The research that is most closely related to ours in terms of focus is Dean and Lovely (2010). They examine whether production fragmentation and processing trade have played a role in making China's exports cleaner. They find that China's exports have shifted toward highly fragmented sectors that are relatively clean. Their findings are very much in line with our results. The difference is that Dean and Lovely (2010) employ a model at the aggregate level, which is estimated with econometric techniques. Their dataset covers annual data for the period 1995-2004. In contrast, this chapter provides - to our knowledge - the first attempt at quantifying the relationship between trade, CO_2 emissions, and production fragmentation at a detailed industry level.

The remainder of the chapter is structured as follows. Section 5.2 introduces the set-up of the model and discusses the data. Section 5.3 presents our results for the CO_2 emissions and the value added generation, and compares their ratio for the different types of exports. Section 5.4 summarizes our findings and concludes.

5.2 Methodology

Our starting point is a unique, tripartite IO table for China in 2002, the structure of which is outlined in Figure 5.2. For each of 28 industries, three types (or classes) of production are distinguished: production for domestic use only (indicated by superscript *D*); production of processing exports (*P*); and the combination of production of non-processing exports and production by foreign-invested enterprises for domestic use (termed 'other production' and indicated by superscript *N*).

the bilateral trade statistics. See Rodrik (2006), Schott (2006), and Feenstra and Hong (2010) for estimating the exports' contribution to Chinese economic growth. Lau et al. (2006, 2007), Zhu et al. (2007), and Koopman et al. (2008) focus on the characteristics of China's processing exports and emphasize the relatively small contribution to value added.

Figure 5.2 The structure of China's tripartite input-output table*

	Intermediate use			Final use		
	D	*P*	*N*	*DFD*	*EXP*	*TOT*
D	$\mathbf{Z}^{DD}$	$\mathbf{Z}^{DP}$	$\mathbf{Z}^{DN}$	$\mathbf{f}^{D}$	0	$\mathbf{x}^{D}$
P	0	0	0	0	$\mathbf{e}^{P}$	$\mathbf{x}^{P}$
N	$\mathbf{Z}^{ND}$	$\mathbf{Z}^{NP}$	$\mathbf{Z}^{NN}$	$\mathbf{f}^{N}$	$\mathbf{e}^{N}$	$\mathbf{x}^{N}$
IMP	$\mathbf{M}^{D}$	$\mathbf{M}^{P}$	$\mathbf{M}^{N}$	$\mathbf{f}^{M}$	0	$\mathbf{x}^{M}$
VA	$(\mathbf{v}^{D})'$	$(\mathbf{v}^{P})'$	$(\mathbf{v}^{N})'$			
TOT	$(\mathbf{x}^{D})'$	$(\mathbf{x}^{P})'$	$(\mathbf{x}^{N})'$			

**D* = industries producing for domestic use only; *P* = industries producing processing exports; *N* = industries producing non-processing exports and production of foreign-invested enterprises for domestic purposes; *DFD* = domestic final demands; *EXP* = exports; *TOT* = gross industry outputs (and total imports in the column *TOT*); *IMP* = imports; and *VA* = value added. The input-output table is expressed in monetary units (of 10,000 RMB).

With respect to the last category, foreign-invested enterprises (FIEs) directly export approximately half of their production as processing exports. The remaining half is used as domestic intermediate input or is for domestic final demand purposes. Note that this other production of FIEs is grouped with the production of non-processing exports and not with the production for domestic use only. Because the inputs for most of this other production by FIEs are imported (Wang and Lv, 2005; Yang and Pei, 2007), the input structure of other production of FIEs is more similar to that of the production of non-processing exports than to that of the production for domestic use only. Such treatment is in line with the theory on heterogeneous firms (as developed by Melitz, 2003, see also Ahn et al., 2011).

The framework is similar to that of an interregional IO (IRIO) table with three regions (see Miller and Blair, 2009). Each class (or region in the IRIO case) has the same industries and produces the same goods and services. Our dataset covers n = 28 industries, see 5.A for the classification scheme. The element z_{ij}^{RS} of the $n \times n$ matrix $\mathbf{Z}^{RS}$ gives the domestic delivery of industry i in class R to industry j in class S (R, S =

D, P, N).[6] Note that $\mathbf{Z}^{PD} = \mathbf{Z}^{PP} = \mathbf{Z}^{PN} = 0$. The elements f_i^D and f_i^N of the $n\times 1$ vectors $\mathbf{f}^D$ and $\mathbf{f}^N$ give the domestic final demands for good *i* produced in class *D* and in class *N*, respectively. The domestic final demands comprise rural household consumption, urban household consumption, government consumption, gross fixed capital formation (i.e., investments), and changes in stocks and inventories. The elements e_i^P and e_i^N of the vectors $\mathbf{e}^P$ and $\mathbf{e}^N$ give the exports of good *i* produced in class *P* and in class *N*, respectively. The element x_i^R of the vector $\mathbf{x}^R$ gives the domestic gross output of industry *i* in class *R* (= *D*, *P, N*). The element v_i^R of the (row) vector $(\mathbf{v}^R)'$ gives the value added in industry *i* produced in class *R* (= *D*, *P, N*), which consists of wages and salaries, capital depreciation, net taxes on production and the operating surplus. The imports consist of two types, imported inputs of good *i* by industry *j* in class *R* (= *D*, *P, N*) are given by element m_{ij}^R of the matrix $\mathbf{M}^R$, and imports of good *i* that go directly to the final users are given by the element f_i^M of the vector $\mathbf{f}^M$. Aggregation over the classes gives the 'ordinary' national IO table (in the same way as aggregation over regions does for an IRIO table), the structure of which is outlined in Figure 5.3.

Figure 5.3 The structure of China's ordinary national input-output table

	Intermediate use	Final use		
		DFD	*EXP*	*TOT*
	$\mathbf{Z}$	$\mathbf{f}$	$\mathbf{e}$	$\mathbf{x}$
IMP	$\mathbf{M}$	$\mathbf{f}^M$	0	$\mathbf{x}^M$
VA	$\mathbf{v}'$			
TOT	$\mathbf{x}'$			

[6] Matrices are indicated by boldfaced capital letters (e.g., **Z**), vectors are columns by definition and are indicated by boldfaced lowercase letters (e.g., **x**), and scalars (including elements of matrices or vectors) are indicated by italicized lowercase letters (e.g., *c* or *α*). A prime indicates transposition (e.g., $\mathbf{x}'$) and a hat (or circumflex) indicates a diagonal matrix (e.g., $\hat{\mathbf{x}}$) with the elements of a vector (i.e., **x**) on its main diagonal and all other entries equal to zero.

The official, published IO table, only contains aggregate information on intermediate deliveries (**Z**), domestic final demands (**f**), exports (**e**), total output (**x**), and value added (**v**). The construction of the tripartite IO table from the ordinary IO table involves three major steps.[7] These are: (i) to determine the vectors of total outputs, final demands, and value added for the three classes of production; (ii) to obtain aggregate vectors of various intermediate uses; and (iii) to apply the RAS method (see Miller and Blair, 2009) to balance the IO relations, taking the vectors of total outputs and imports of the different classes of production as control variables. Next, we will briefly describe the assumptions that were made in constructing the tripartite IO table.

First, the value of the re-exports is assumed to be zero. According to China Customs, the re-exports are a negligible portion of total exports (less than 1% in 2002). Second, because of certain regulations, processing imports can only be used for the production of processing exports. Non-processing imports can be used both as intermediate inputs and for household consumption. Consequently, all imported goods for household consumption are non-processing imports. Third, the distribution of the imported goods is based on two assumptions: (i) as originally proposed by Chen et al. (2001), all processing imports are classified as imported intermediates;[8] and (ii) as originally proposed by Dean et al. (2008), the UN BEC method is applied to identify the intermediate inputs within the non-processing imports.[9] Fourth, input coefficients have to be estimated for each of the three classes of production. Custom Statistics not only provides total imports by commodity, but also imports (by commodity) that are used for producing processing exports. These data are available because imports for processing exports are exempted from import duties and are therefore carefully tracked by the authorities. On the basis of these import data, the matrix $\mathbf{M}^P$ is estimated. Unfortunately, data for estimating the matrices $\mathbf{M}^D$ and $\mathbf{M}^N$ are limited. The overall rates of imported inputsare obtained from aggregate data for

[7] A full exposition of the procedure for developing the tripartite IO table is beyond the scope of this chapter. The details are given in Lau et al. (2006, 2007). See Yang and Pei (2007) or Yang et al. (2012) for applications.

[8] Chen et al. (2001) is the presentation that was at the heart of Chen et al. (2009).

[9] Dean et al. (2008) is the original working paper that was later published as Dean et al. (2011). The UN BEC method splits commodities into three categories, namely for intermediate use, for household consumption, and for investment purposes.

non-processing exportsand by residual imputation for domestic use.[10] A modified RAS (bi-proportional) procedure is used to estimate and reconcile the import matrices with the margins (which are known from the available statistics). Fifth, the production of FIEs consists of processing exports and 'other production'. On the basis of observed similarities (see Wang and Lv, 2005), it is assumed that the production structure of this 'other production' (which is used domestically) is the same as the production structure of non-processing exports.

Whereas the table used in this chapter splits the ordinary IO table into three parts, the table developed in Koopman et al. (2008) adopts a split into two parts. When comparing the two approaches, processing exports are dealt with in more or less the same way. The key difference is that Koopman et al. (2008) (implicitly) assume that the same production structure applies to both non-processing exports and domestic production.[11] The differences between foreign-invested enterprises and domestic firms are therefore absent in their table. In contrast, our table is constructed to purposely split the production into three separate classes because of differences in their production structures (see Lau et al., 2006, 2007).[12] Our table thus provides an additional class, but has fewer industries (28 versus 83).[13] Differences exist also in the techniques that are applied to estimate the tables. For our table, the national IO structure is taken as a starting point and vectors with control variables are obtained from Customs statistics, after which the RAS method is applied to balance the table. The procedure in Koopman et al. (2008) is based on quadratic programming techniques.[14]

We next introduce the models used to derive the matrices of input coefficients. For the ordinary IO table we have $\mathbf{A} = \mathbf{Z}\hat{\mathbf{x}}^{-1}$ and its element $a_{ij} = z_{ij} / x_j$ gives the

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[10] That is, the row sums of the matrices $\mathbf{M}^P$ and $\mathbf{M}^N$ (in Figure 5.2) are subtracted from the row sums of $\mathbf{M}$ (in Figure 5.3).

[11] Although this assumption may become plausible in the future, the input structure for China's 'ordinary' exports is quite different from the production structure for domestic use in 2002 (and the years thereafter).

[12] The National Bureau of Statistics endorses the assumptions that have been made. As a matter of fact, they have announced to adopt the methodology that was used for constructing the 2002 tripartite IO table in developing a similar table for 2007.

[13] It should be stressed that the tripartite IO table covers 42 industries. Limitations in the emission data forced us to aggregate them into the 28 industries listed in 5.A.

[14] The RAS method is a commonly used technique for balancing in the IO literature (see Lenzen et al., 2009). While quadratic programming technique has almost the same function as the RAS method, it has the advantage that it can handleconflicting external data (see Canning and Wang, 2005), albeit in a 'mechanical' way. For non-conflicting data (or when conflicts have been solved 'manually') the two methods yield very similar results.

input of good i per unit of output of industry j. For the tripartite IO table we have $\mathbf{A}^{RS} = \mathbf{Z}^{RS}(\hat{\mathbf{x}}^{S})^{-1}$ with R, S = D, P, N. Its element $a_{ij}^{RS} = z_{ij}^{RS} / x_{j}^{S}$ gives the input of good i from class R per unit of output of industry j in class S. We write $\overline{\mathbf{A}}$ for the $3n \times 3n$ input matrix in the tripartite case and from Figure 5.2 it follows that

$$\overline{\mathbf{A}} = \begin{bmatrix} \mathbf{A}^{DD} & \mathbf{A}^{DP} & \mathbf{A}^{DN} \\ 0 & 0 & 0 \\ \mathbf{A}^{ND} & \mathbf{A}^{NP} & \mathbf{A}^{NN} \end{bmatrix} \tag{5-1}$$

For the ordinary IO table in Figure 5.3, we now have $\mathbf{x} = \mathbf{A}\mathbf{x} + (\mathbf{f} + \mathbf{e})$, or $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}(\mathbf{f} + \mathbf{e}) = \mathbf{L}(\mathbf{f} + \mathbf{e})$, where $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief inverse. The outputs that are necessary for satisfying the domestic final demands and the exports, are given by $\mathbf{Lf}$ and $\mathbf{Le}$, respectively.

Let the element r_i of the (row) vector $\mathbf{r}'$ represent the CO_2 emissions by industry i. The direct emission coefficients are obtained as $\boldsymbol{\mu}' = \mathbf{r}'\hat{\mathbf{x}}^{-1}$ and its element $\mu_i = r_i / x_i$ gives the emissions by industry i per unit of its gross output. The total amount of emissions due to exports, for example, are then given by the scalar $\boldsymbol{\mu}'\mathbf{Le}$. The ith element of the row vector $\boldsymbol{\mu}'\mathbf{L}\hat{\mathbf{e}}$ gives the total emissions necessary for the exports of product i, and the ith element of the column vector $\hat{\boldsymbol{\mu}}\mathbf{Le}$ gives the emissions by industry i necessary for all exports. In our application, we will use

$$\mathbf{g}^{(\mathbf{f})} = \hat{\boldsymbol{\mu}}\mathbf{Lf} \tag{5-2a}$$

$$\mathbf{g}^{(\mathbf{e})} = \hat{\boldsymbol{\mu}}\mathbf{Le} \tag{5-2b}$$

In the same fashion, we find for the tripartite IO table in Figure 5.2 that the Leontief inverse is given by

$$\overline{\mathbf{L}} = (\mathbf{I} - \overline{\mathbf{A}})^{-1} = \begin{bmatrix} \mathbf{L}^{DD} & \mathbf{L}^{DP} & \mathbf{L}^{DN} \\ 0 & \mathbf{I} & 0 \\ \mathbf{L}^{ND} & \mathbf{L}^{NP} & \mathbf{L}^{NN} \end{bmatrix} \tag{5-3}$$

The direct emission coefficients are given by $(\boldsymbol{\mu}^D)' = (\mathbf{r}^D)'(\hat{\mathbf{x}}^D)^{-1}$ for class D producers (and similar expressions for class P and N producers). The emissions that are necessary for each of the four categories of final use in Figure 5.2 are given by

$$\mathbf{g}^{(\mathbf{f}^D)} = (\hat{\boldsymbol{\mu}}^D \mathbf{L}^{DD} + \hat{\boldsymbol{\mu}}^N \mathbf{L}^{ND})\mathbf{f}^D \tag{5-4a}$$

$$\mathbf{g}^{(\mathbf{f}^N)} = (\hat{\boldsymbol{\mu}}^D \mathbf{L}^{DN} + \hat{\boldsymbol{\mu}}^N \mathbf{L}^{NN})\mathbf{f}^N \tag{5-4b}$$

$$\mathbf{g}^{(\mathbf{e}^P)} = (\hat{\boldsymbol{\mu}}^D \mathbf{L}^{DP} + \hat{\boldsymbol{\mu}}^P + \hat{\boldsymbol{\mu}}^N \mathbf{L}^{NP})\mathbf{e}^P \tag{5-4c}$$

$$\mathbf{g}^{(\mathbf{e}^N)} = (\hat{\boldsymbol{\mu}}^D \mathbf{L}^{DN} + \hat{\boldsymbol{\mu}}^N \mathbf{L}^{NN})\mathbf{e}^N \tag{5-4d}$$

where, for example, the ith element of the column vector in (5-4c) indicates the emissions by all industries i (i.e., in class D, P and N) that are necessary for satisfying the processing exports (i.e., foreign demand for goods produced in class P).

For calculating the emissions in China that correspond to the different categories (such as processing exports and non-processing exports), we have used the data on estimated emissions from Peters et al. (2006, 2007). As indicated in their report, the CO_2 emissions are estimated based on energy use, the data for which were obtained from official statistics (Energy Statistics Yearbooks of the Chinese National Bureau of Statistics, complemented with information from the IPCC, the IEA, and CCCCS, 1999). For each fuel, they multiplied the carbon emission factor with the fraction of carbon oxidized in each sector and with the energy consumption in each sector to arrive at the CO_2 emissions. It should be stressed that the estimated CO_2 emissions may contain potential biases. These are due to the reliability of the energy data, the reallocation of energy use over the industries, the fuel-specific carbon emission factors, and the fraction of fuel-specific carbon oxidized in each sector.[15] Our results for the sizes of the various emissions should thus be interpreted with some caution. The shares, however, are unlikely to be affected by these uncertainties.

The emissions data do not distinguish between the three classes of production. Therefore we have run two sets of calculations. The first set assumes that the emission coefficient for industry $i$is the same in each class. That is, we have used identical

[15] Peters et al. (2006) also report several specific uncertainties they encountered in estimating the sectoral carbon dioxide emissions.

coefficients $\boldsymbol{\mu}^D = \boldsymbol{\mu}^P = \boldsymbol{\mu}^N = \boldsymbol{\mu}$, where $\boldsymbol{\mu}$ is the vector of emission coefficients based on Peters et al. (2006). Hereafter, this case is indicated as 'identical coeffs'.

For the second set of calculations, we have estimated separate coefficients for each of the three classes (hereafter indicated as'separatecoeffs'). The idea is that product *i* has a comparable output value no matter whether it is produced in class *D* or *P*. However, in class *P* the production of this good relies heavily on imported inputs (i.e., processing imports) and some labor for assembly. Only a very small part of its production chain is situated in China, in contrast to production in class *D* where a large part of the production chain is in China. Therefore it seems plausible that also the emissions of industries in class *P* are only a fraction of those of industries in class *D*, as suggested in Converse (1971). The industries in class *N* are expected to take an intermediate position. The estimation of the emission coefficients is based on the extent to which an industry relies on domestic intermediate inputs. In the overall case (corresponding to Figure 5.3) the domestic intermediate inputs of industry *i* are given by the *i*th element of the row vector $\boldsymbol{\rho}' = \mathbf{s}'\mathbf{A}$, where $\mathbf{s}$ indicates the summation vector consisting of ones. The domestic intermediate inputs in each of the three classes is given by $(\boldsymbol{\rho}^D)' = \mathbf{s}'(\mathbf{A}^{DD} + \mathbf{A}^{ND})$, $(\boldsymbol{\rho}^P)' = \mathbf{s}'(\mathbf{A}^{DP} + \mathbf{A}^{NP})$ and $(\boldsymbol{\rho}^N)' = \mathbf{s}'(\mathbf{A}^{DN} + \mathbf{A}^{NN})$. The estimated emission coefficients are then obtained as

$$\mu_i^D = \frac{\rho_i^D}{\rho_i}\mu_i, \quad \mu_i^P = \frac{\rho_i^P}{\rho_i}\mu_i, \text{ and } \quad \mu_i^N = \frac{\rho_i^N}{\rho_i}\mu_i \tag{5-5}$$

Note that these class-specific emission coefficients still yield the correct total emissions in each industry. That is,

$$\mu_i^D x_i^D + \mu_i^P x_i^P + \mu_i^N x_i^N = \mu_i x_i = r_i \tag{5-6}$$

the proof of which is given in 5.B.

Finally, a similar set of calculations has been carried out for the value added in each industry. That is, define the value added coefficients as $\boldsymbol{\upsilon}' = \mathbf{v}'\hat{\mathbf{x}}^{-1}$, where $\mathbf{v}$ is the value added vector from Figure 5.3. Replacing the vector $\boldsymbol{\mu}$ by $\boldsymbol{\upsilon}$ in equation (5-2) gives the value added in each industry that is generated by the domestic final demands and by the exports, respectively. In the case of Figure 5.2, we have $(\boldsymbol{\upsilon}^R)' = (\mathbf{v}^R)'(\hat{\mathbf{x}}^R)^{-1}$ with R = D, P, N, and replacing $\boldsymbol{\mu}^R$ by $\boldsymbol{\upsilon}^R$ in equation (5-4) provides the vectors with values added for each of the four categories of final use.

5.3 The results for China in 2002

5.3.1 Carbon dioxide emissions and value added generation

Table 5.1 presents the results at the aggregate (national) level, i.e. obtained from summing over the industries.

Table 5.1 Overview of results at the aggregate level, carbon dioxide emissions and values added for each final demand category*

	Tripartite IO table				Ordinary IO table		Total
	DFD		*EXP*		*DFD*	*EXP*	
Final demand category	$\mathbf{f}^D$	$\mathbf{f}^N$	$\mathbf{e}^P$	$\mathbf{e}^N$	$\mathbf{f}$	$\mathbf{e}$	
Corresponding equation	(5-4a)	(5-4b)	(5-4c)	(5-4d)	(5-2a)	(5-2b)	
CO_2							
separate coefficients	2,513	464	71	358	2,716	690	3,406
(as % of total)	(73.8)	(13.6)	(2.1)	(10.5)	(79.7)	(20.3)	(100.0)
identical coefficients	2,498	444	96	368			3,406
(as % of total)	(73.3)	(13.0)	(2.8)	(10.8)			(100.0)
Value added							
nominal	9,847	720	374	1,245	9,838	2,348	12,186
(as % of total)	(80.8)	(5.9)	(3.1)	(10.2)	(80.7)	(19.3)	(100.0)

*CO_2 emissions are in Mt; values added are in billion RMB. For the ordinary IO table, the distinction between separate and identical coefficients does not apply. Totals are the sum of the columns corresponding to (5-4a) – (5-4d) or, equivalently, those corresponding to (5-2a) – (5-2b). *DFD* = domestic final demands; *EXP* = exports. $\mathbf{f}^D$ = domestic final demands produced by class *D*; $\mathbf{f}^N$ = domestic final demands produced by class *N*; $\mathbf{e}^P$ = exports produced by class *P*; $\mathbf{e}^N$ = exports produced by class *N*. $\mathbf{f}$ = domestic final demands; $\mathbf{e}$ = exports.

It gives the CO_2 emissions and the values added that can be ascribed to the domestic final demands (such as private consumption, private investments, and government expenditures) and to the exports. Using the tripartite IO table for China in 2002, we have four final demand categories: domestic final demands for goods and services produced by enterprises that produce for domestic use only ($\mathbf{f}^D$); domestic final demands produced by enterprises in class N ($\mathbf{f}^N$, which reflects the domestic final demands produced by foreign-invested enterprises); processing exports ($\mathbf{e}^P$); and non-processing exports ($\mathbf{e}^N$). The formulas for calculating the emissions at the industry level are given by equations (5-4a)–(5-4d), respectively.

As mentioned, the tripartite IO table for China is a unique table that takes the special characteristics of processing exports into full account. Usually, calculations have to be done using the ordinary national IO table, which sketches an average input structure. In order to highlight the consequences of this, we have calculated the emissions and values added generated in satisfying domestic final demands (**f**) and the exports (**e**), using the ordinary IO table and the corresponding equations (5-2a) and (5-2b). For the emissions in the tripartite framework, we have done two sets of calculations. The results in the rows 'separate coeffs' are obtained from using class-specific emission coefficients that have been estimated according to equation (5-5), the results in the rows 'identical coeffs' are obtained from using the assumption that emission coefficients are the same across classes (i.e., $\boldsymbol{\mu}^D = \boldsymbol{\mu}^P = \boldsymbol{\mu}^N = \boldsymbol{\mu}$).

Peters et al. (2006) report that 3406.3 Mt of CO_2 was emitted in 2002 by industries, while 100.4 Mt was emitted by urban residents, and 80.6 by rural residents (i.e., 95%, 3% and 2% of the total emissions, respectively). The focus in this study is on the emissions generated by industry production which comprises 95% of total emissions in 2002.

Several observations follow from the results in Table 5.1. First, the role of exports in generating Chinese CO_2 emissions has previously been overestimated. Whereas Weber et al. (2008) report that about 33% of the production-related CO_2 emissions in 2005 can be ascribed to exports (the contribution is 21% in 2002), our results - in the rows 'separate coeffs', i.e. using class-specific direct emission coefficients - indicate that this is only 12.6%.[16] This implies that 87.4% is due to domestic final demands. Second, the processing exports are responsible for only 16.6% of the export-related CO_2 emissions, whereas processing exports account for no less

[16] 12.6% is 2.1% + 10.5%, i.e. the sum of the figures in parentheses in the row for separate coefficients and the columns for expressions (5-4c) and (5-4d).

than 55.3% of the total exports in 2002 (see NBS, 2009).[17] Third, the value added generated by processing exports amounts to 23.1% of that generated by all the exports.[18] When compared to the non-processing exports, this implies that processing exports generate less value added on the one hand, but fewer emissions on the other. We will come back to this issue later.

Fourth, if the tripartite IO table would not have been available - which is the case for almost all other countries in the world - we would have been forced to use the ordinary national IO table. In that case, the export-related CO_2 emissions would have been reported as 20.3% of all production-related CO_2 emissions (which corresponds to the 21% for 2002 as reported in Weber et al., 2008). This is an overestimation by no less than 61%. The reason is that the ordinary IO table is obtained by aggregating the tripartite table, using gross outputs as weights. Because the gross outputs of the classes *P* and *N* are relatively small, the average production (or input) structure and the direct emission coefficients are very similar to those for domestic use only (in *D*).

Fifth, when we compare the results in the rows 'separate coeffs' with those in the rows 'identical coeffs' we see that the differences are surprisingly small at the aggregate level. In the case of identical emission coefficients, using the ordinary IO table still yields an overestimation by 49% and the share of processing exports in the total amount of export-related emissions is still minor (20.7%). So, when accounting China's CO_2 emissions, what matters most is that outsourcing is adequately taken into account (by using the tripartite IO table instead of the ordinary IO table). The aggregate results appear to be fairly insensitive to the assumptions that had to be made because direct emission coefficients for the three separate classes are not available.[19]

This study focuses on China's CO_2 emissions embodied in its trade flows. It should be mentioned that one might also be interested in the worldwide pollution embodied in China's exports, because CO_2 emissions are global. Using the ordinary national IO table, the imports from the rest of the world (RoW) necessary to produce China's exports are given by **MLe**. If we denote the direct emission coefficients in

[17] The 16.6% is obtained from 71/(71+358), i.e. the emissions due to processing exports as a share of the emissions due to all exports.
[18] The 23.1% is obtained from 374/(374+1245), i.e. the vale added due to processing exports as a share of the value added due to all exports.
[19] As a robustness check, we have also applied energy-consumption coefficients which led to the same conclusion, thus supporting our argument. The detailed results for energy-consumption are not shown due to space limitations, but are available upon request.

RoW by $\boldsymbol{\mu}^{ROW}$ the emissions generated in RoW for China's exports are $\hat{\boldsymbol{\mu}}^{ROW}\mathbf{MLe}$.[20] Adding (5-2b) gives the worldwide emissions, i.e. $\hat{\boldsymbol{\mu}}\mathbf{Le} + \hat{\boldsymbol{\mu}}^{ROW}\mathbf{MLe}$. The processing exports require emissions in RoW to the amount of $\hat{\boldsymbol{\mu}}^{ROW}(\mathbf{M}^{D}\mathbf{L}^{DP} + \mathbf{M}^{P} + \mathbf{M}^{N}\mathbf{L}^{NP})\mathbf{e}^{P}$ and the emissions in China are given by (5-4c) for the tripartite IO table. A similar expression applies to the non-processing exports $\mathbf{e}^{N}$. We have seen in Table 5.1 that the emissions in China are much smaller for the processing exports than for the non-processing exports (both of which are of a comparable size). This is the case because processing exports rely heavily on imported inputs and thus on emissions in RoW, whereas non-processing exports depend more on domestic inputs and thus on emissions in China. The gap between emissions due to non-processing exports and emissions due to processing exports will be considerably smaller for global emissions than for Chinese emissions. Theoretically the worldwide emissions due to processing exports could be larger than those due to non-processing exports. This would happen if the direct emission coefficients (at least those for the imported products) are larger in the RoW than in China. Calculation (even of a rough approximation) requires emission coefficients in the countries of origin for all the import flows, data for which are lacking at a detailed level. The list of China's major trading partners, however, suggests that China's imports are less emission intensive than their own production. In that case, also the global emissions involved in processing exports are smaller than those involved in non-processing exports.

Table 5.2 gives the CO_2 emissions by each industry for each of the four final demand categories. We included only the results for the tripartite IO table and for the case with class-specific direct emission coefficients. Note that the totals in the bottom row are the same as given in Table 5.1 in the row 'separate coeffs'. It is clear that for all four final demand categories, the bulk of CO_2 is emitted by only five industries. These are: 22 (Production and supply of electricity and heating power); 13 (Non-metal mineral products); 14 (Metals smelting and pressing); 26 (Transport and warehousing); and 12 (Chemicals). Together they emit 83.3% of the CO_2 due to

[20] It should be stressed that this is valid only if China's exports are used just for final demand purposes in RoW (and not as inputs in the production of RoW). Whenever this assumption does not apply (as is the case for China), the expressions only provide an approximation. The correct calculations require the adoption of an inter-country IO framework (see, e.g., Tukker et al., 2009; Peters et al., 2011), which is far beyond the scope of the present chapter.

domestic final demands produced in class *D* and the shares are 92.9% in case of domestic final demands produced in class *N*, 79.0% in case of processing exports and 83.6% in case of non-processing exports.

Table 5.2 CO_2 emissions (Mt) in each industry, per final demand category

	Domestic final demands		Exports		
	$\mathbf{f}^D$	$\mathbf{f}^N$	$\mathbf{e}^P$	$\mathbf{e}^N$	
Equation	(5-4a)	(5-4b)	(5-4c)	(5-4d)	
Industry					Total
1	73	4	1	7	85
2	26	5	1	5	38
3	38	4	0	5	47
4	6	0	0	0	6
5	7	0	0	1	8
6	30	6	1	4	40
7	14	1	2	11	27
8	1	0	0	1	2
9	3	1	0	1	5
10	17	2	2	3	24
11	45	2	1	4	51
12	149	9	7	20	186
13	451	40	9	50	551
14	377	25	5	36	443
15	9	0	0	2	11
16	18	3	0	2	23
17	10	1	0	1	12
18	4	0	0	0	5
19	4	0	0	0	5
20	0	0	0	0	1
21	5	0	0	1	7
22	963	348	25	157	1,493
23	4	1	0	1	5
24	0	0	0	0	1
25	22	0	0	0	23
26	153	9	10	36	208
27	23	2	3	6	33
28	61	3	1	5	70
Total (%)	2,513 (73.8)	464 (13.6)	71 (2.1)	358 (10.5)	3,406 (100.0)

Also the rankings within this top five are almost the same, except for Transport and warehousing (26) which ranks second for CO_2 emissions due to processing exports. This clearly reflects the relatively strong dependence of processing exports on the transport sector. The top ranking for industry 22 is not very surprising, given the fact that coal still dominates electricity production in China (since the mid 1970s, approximately 70% of the primary energy consumption is coal-based). One striking difference is that for the domestic final demands produced by enterprises in class *N* no less than 74.9% of the CO_2 emissions are generated by industry 22, whereas this share ranges between 35% and 45% for the other three final demand categories.

Table 5.3 is similar to Table 5.2 in the sense that it gives the value added (instead of the amount of CO_2 emissions) generated in each industry, for each of the four final demand categories. For example, the processing exports induce domestic production and as a consequence value added is generated in the amount of 22 billion RMB in industry 1 (Agriculture), 6 billion RMB in industry 2 (Coal mining), etc. A striking difference between the two tables is that the top five CO_2 emitting industries (i.e., 22, 13, 14, 26, and 12) play a more modest role in generating value added. Their contribution to value added ranges between 17.3% (of all value added due to $\mathbf{f}^D$) and 25.8% (of all value added induced by $\mathbf{f}^N$). Another difference between the two tables is that the set of top five industries in terms of generating value added differs largely between final demand categories, whereas the top five in terms of CO_2 emissions was the same for all final demand categories.

Our findings indicate that CO_2 emissions are largely determined by production in a small set of industries (i.e., 22, 13, 14, 26, and 12). Due to their large emission intensities they generate the bulk of the CO_2 emissions, which holds irrespective of the product-mix of the final demand vectors. In contrast to this, value added generation is not concentrated in a small set of industries. The value added coefficients (which measure value added per unit of output) are more evenly spread. Final demand vectors with a different product-mix lead to different output patterns across industries, different patterns of value added, and thus to different sets of top contributors.

Table 5.3 Value added (billion RMB) in each industry, per final demand category

	Domestic final demands		Exports		
	$\mathbf{f}^D$	$\mathbf{f}^N$	$\mathbf{e}^P$	$\mathbf{e}^N$	
Equation	(5-4a)	(5-4b)	(5-4c)	(5-4d)	
Industry					Total
1	1,422	76	22	144	1,663
2	160	29	6	33	228
3	187	18	2	24	232
4	59	1	1	2	63
5	66	1	1	6	74
6	338	63	9	40	450
7	113	6	14	90	223
8	92	7	18	47	163
9	73	12	5	18	108
10	172	16	19	30	237
11	92	4	2	8	105
12	467	28	23	64	581
13	156	14	3	17	191
14	319	21	4	31	375
15	112	5	4	21	142
16	292	42	7	25	365
17	204	24	6	20	253
18	142	3	10	17	172
19	242	3	13	16	273
20	13	2	18	11	43
21	44	2	3	8	58
22	256	92	7	42	396
23	5	1	0	1	7
24	18	9	1	1	28
25	649	3	1	6	659
26	503	30	32	117	682
27	642	43	83	161	928
28	3,011	166	63	246	3,486
Total (%)	9,847 (80.8)	720 (5.9)	374 (3.1)	1,245 (10.2)	12,186 (100.0)

5.3.2 Carbon dioxide emissions *versus* value added generation

One of the overall findings in Table 5.1 was that CO_2 emissions and value added induced by processing exports are smaller than the amounts induced by non-processing exports. However, the CO_2 emissions were several times smaller whereas value added generation was approximately two times smaller. In this section, we will carry out a more detailed analysis of the CO_2 emissions per RMB of value added generation. Similar calculations were done by Muller et al. (2011) who computed the gross external damage relative to value added by sector in the US.

From equation (5-4a), the ith element of the row vector $(\boldsymbol{\mu}^D)'\mathbf{L}^{DD} + (\boldsymbol{\mu}^N)'\mathbf{L}^{ND}$ gives the total amount of CO_2 emissions per unit of final demand for good i produced in class D (for domestic use only). In the same fashion, the ith element of the row vector $(\boldsymbol{\upsilon}^D)'\mathbf{L}^{DD} + (\boldsymbol{\upsilon}^N)'\mathbf{L}^{ND}$ gives the corresponding amount of value added. Their ratio

$$\xi_i^D = \frac{[(\boldsymbol{\mu}^D)'\mathbf{L}^{DD} + (\boldsymbol{\mu}^N)'\mathbf{L}^{ND}]_i}{[(\boldsymbol{\upsilon}^D)'\mathbf{L}^{DD} + (\boldsymbol{\upsilon}^N)'\mathbf{L}^{ND}]_i} \tag{5-7a}$$

expresses how much CO_2 is emitted per unit of value added, both corresponding to the final demand for good i produced in class D (i.e., f_i^D). Note that $[\ldots]_i$ indicates the ith element of the vector between brackets.

For the final demands for good i in the other classes (i.e., e_i^P in class P, and f_i^N or e_i^N in class N), we have the following formulas:

$$\xi_i^P = \frac{[(\boldsymbol{\mu}^D)'\mathbf{L}^{DP} + (\boldsymbol{\mu}^P)' + (\boldsymbol{\mu}^N)'\mathbf{L}^{NP}]_i}{[(\boldsymbol{\upsilon}^D)'\mathbf{L}^{DP} + (\boldsymbol{\upsilon}^P)' + (\boldsymbol{\upsilon}^N)'\mathbf{L}^{NP}]_i} \tag{5-7b}$$

$$\xi_i^N = \frac{[(\boldsymbol{\mu}^D)'\mathbf{L}^{DN} + (\boldsymbol{\mu}^N)'\mathbf{L}^{NN}]_i}{[(\boldsymbol{\upsilon}^D)'\mathbf{L}^{DN} + (\boldsymbol{\upsilon}^N)'\mathbf{L}^{NN}]_i} \tag{5-7c}$$

From the results in Table 5.1 we can readily calculate that the average for the processing exports vector $\mathbf{e}^P$ is 0.19 (ton/1,000 RMB), whereas it is 0.29 (ton/1,000 RMB) for the vector of non-processing exports $\mathbf{e}^N$. It should be noted, however, that these averages use value added shares as weights. That is, for the non-processing exports, for example,

$$0.29 = \frac{358}{1245} = \Sigma_i \xi_i^N w_i^N \quad \text{with} \quad w_i^N = \frac{[(\mathbf{\upsilon}^D)'\mathbf{L}^{DN} + (\mathbf{\upsilon}^N)'\mathbf{L}^{NN}]_i e_i^N}{\Sigma_i [(\mathbf{\upsilon}^D)'\mathbf{L}^{DN} + (\mathbf{\upsilon}^N)'\mathbf{L}^{NN}]_i e_i^N} \tag{5-8}$$

where w_i^N indicates the value added generated by final demand e_i^N as a share of the value added generated by all non-processing exports.

Instead of using value added shares as weights, we may also take the final demand components as the basis of the weights. For the processing exports this yields

$$\Sigma_i \xi_i^P w_i^P \quad \text{with} \quad w_i^P = \frac{e_i^P}{\Sigma_i e_i^P} \tag{5-9}$$

The results are given in Table 5.4. Our first observation is that the ratios for Nonmetal mineral products (product 13) and Electricity and heating power production and supply (22) are outliers. On average, they are 1.5 and 2.3, while for almost any other product it is less than 0.5 (except Metals smelting and pressing, product 14, with an average of 0.8). Hence, each RMB of value added due to the domestic final demand or export of electricity yields at least four times as much CO_2 emissions as a RMB of value added generated by the final demand for any other product (except product 14). For nonmetal mineral products this is three times as much as for any other product (similar findings are reported in Muller et al., 2011).

Second, we observe that the ratios of CO_2 emissions per 1,000 RMB of value added show a pattern within each row that is quite similar across industries. That is, the ratio is the smallest for processing exports and, roughly speaking, it is 30-50% larger in the columns *D* and *N* (which are very comparable). The exceptions - with differences that are substantially larger - are industries 24 (Water production and supply), 4 (Metal ore mining), and 15 (Metal products).

Third, note that the ratios ξ_i^N hold for both the domestic (f_i^N) and the foreign (e_i^N) final demands for goods produced by class *N* enterprises. The weighted averages, however, show an enormous difference where one is roughly twice as large as the other. Clearly, the weighted averages are expected to differ for the two cases because the weights are based on the vectors $\mathbf{f}^N$ and $\mathbf{e}^N$, as follows from equations (5-8) and (5-9).

Table 5.4 CO_2 emissions (tons) per 1,000 RMB of value added due to the final demands for product *i*, per final demand category

	ξ_i^D	ξ_i^P	ξ_i^N	
Equation	(5-7a)	(5-7b)	(5-7c)	
Using 'separate' emission coefficients defined in equation (5-5)				
Product: 1	0.15	0.12	0.14	
2	0.36	0.21	0.40	
3	0.32	0.22	0.36	
4	0.43	0.21	0.54	
5	0.31	0.19	0.35	
6	0.18	0.16	0.17	
7	0.26	0.20	0.26	
8	0.18	0.15	0.18	
9	0.25	0.18	0.24	
10	0.26	0.19	0.25	
11	0.40	0.33	0.49	
12	0.44	0.33	0.50	
13	1.45	1.36	1.61	
14	0.81	0.57	0.91	
15	0.50	0.22	0.52	
16	0.36	0.20	0.40	
17	0.32	0.20	0.32	
18	0.36	0.21	0.38	
19	0.26	0.22	0.32	
20	0.22	0.14	0.23	
21	0.30	0.21	0.29	
22	2.26	2.21	2.35	
23	0.50	0.41	0.54	
24	0.45	0.15	0.59	
25	0.43	0.29	0.43	
26	0.33	0.30	0.33	
27	0.15	0.11	0.15	
28	0.15	0.10	0.14	
Weighted averages (Weights based on):	$\mathbf{f}^D$	$\mathbf{e}^P$	$\mathbf{f}^N$	$\mathbf{e}^N$
Value added shares, equation (5-8)	0.26	0.19	0.64	0.29
Final demand shares, equation (5-9)	0.26	0.21	0.61	0.32
Using 'identical' emission coefficients				
Weighted averages				
Value added shares, equation (5-8)	0.25	0.26	0.62	0.30
Final demand shares, equation (5-9)	0.25	0.28	0.59	0.33

The size of the difference, however, suggests that the product-mix of the two final demand vectors shows some remarkable differences. It turns out that the share of electricity (industry 22, with an outstanding CO_2 emissions to value added ratio of 2.35) is substantial for domestic final demands (13%) and zero for non-processing exports (0%).[21] Fourth, observe that it makes little difference whether the value added shares or the final demand (either domestic or foreign) shares are used as weights in determining the overall averages.

It should be emphasized that the product-specific results in Table 5.4 are obtained by using emission coefficients (for each of the three classes) that were estimated according to equation (5-5). The assumption that the emission intensities are proportional to the use of domestic inputs was an essential part of (5-5). Consequently, the production of processing exports, for example, depends little on domestic inputs and thus has relatively small emission coefficients. Because class-specific emission data are not available, we cannot test the validity of the assumption (although it has been suggested in the literature, see Converse, 1971). In any case, it should be noted that our results may depend on this assumption.[22]

To examine whether (and the extent to which) this is the case we have also run the calculations with emission coefficients that are the same for each of the three production classes. The aggregate results in Table 5.1 appeared not to be very sensitive, as discussed before. For Table 5.4 we find that the results are very similar qualitatively, but not quantitatively. That is, the gap between the ratios for processing exports (in column *P*) and the ratios for other types of final demand (in columns *D* and *N*) has considerably decreased. Removing the assumption that the emission intensities are proportional to the use of domestic inputs increases the emission coefficients for producing processing exports. This is also reflected by the weighted averages (shown in the bottom part of Table 5.4). When separate emission coefficients are used, the average ratio of emissions to value added for processing exports is 34% smaller than the ratio for non-processing exports. When identical coefficients are used, the gap reduces but still amounts to 13%.

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[21] The benchmark table reports that the export value of electricity (industry 22) takes only 0.4% of the total sales (both domestic and foreign) of this industry.

[22] Theoretically speaking, it would be possible that a country specializes in the emission intensive parts of the production process. This trade-based version of the pollution haven hypothesis was rejected by Dietzenbacher and Mukhopadhyay (2007) for India. They found that an average dollar of exports generates less emissions in India than an average dollar of imports reduces emissions in India. Similar findings have been reported by Temurshoev (2006) for China.

From a policy perspective it follows that stimulating processing trade would be a good choice in terms of Chinese environmental management.[23] Every RMB of value added that stems from processing exports generates considerably less CO_2 emissions than one RMB of value added due to non-processing exports. One could even go a step further by promoting processing trade of goods that have a very low CO_2 to value added ratio in column *P* of Table 5.4, such as the products from industries 1 (Agriculture), 20 (Instruments, meters, cultural and office machinery), and 8 (Wearing apparel, leather, furs, and related products).

5.4 Summary and conclusions

China's role in world trade has rapidly grown in recent years. For example, exports grew annually by almost 20% between 2001 and 2010 (compared with 9% for the world as a whole). In policy debates it has been suggested that China's emissions are increasingly caused by demand from foreign countries - importing Chinese goods and services. At the same time, no less than 55% of all exports in 2002 were related to outsourcing. We have argued that producing these processing exports largely relies on imports (of raw materials and intermediate products) and involves little domestic activity. Hence these exports generate relatively little value added and emissions.

The input-output framework is the appropriate tool to calculate the amount of emissions that are (directly and indirectly) due to domestic final demand (including consumption and investments) and exports. Using an ordinary input-output table we found that 20.3% of the CO_2 emissions in 2002 were due to exports. However, the ordinary input-output table cannot make a distinction between the production of processing exports, production for domestic use only, and other production (including production of non-processing exports and production of foreign-invested enterprises for domestic purposes). These three classes of production have very different

[23] It should be stressed that China's role in processing trade will probably not make much difference in terms of global emissions. The part of the production chain that takes place in China would have generated a similar amount of emissions if it had taken place in another country. Global emissions may be affected, however, when the question is whether China should focus on ordinary exports or on processing exports. When producing ordinary exports, a substantial part of the production chain takes place in China and relies, for example, on coal-based power plants. Producing processing exports largely depends on processing imports which - in the case of China - mainly come from relatively more advanced economies such as Japan, Korea, and Chinese Taipei, where production techniques are generally cleaner than in China. A full evaluation of the differences in global emissions would require an inter-country IO model (e.g., the WIOD database: www.wiod.org), which is beyond the scope of this study.

production structures and emission patterns, and their distinction should be taken into full account. Use of a special tripartite input-output table (see Lau et al., 2006, 2007, for details) allowed us to make this distinction. We found that only 12.6% of the CO_2 emissions in 2002 were due to exports. Hence, not taking the distinction between the different types of production into account yields an overestimation of the exports' contribution by 61%, this is our first major finding.[24]

Our second major finding was that production for processing exports is relatively clean.[25] For example, processing exports were found to generate only 16.6% of all export-related CO_2 emissions and 23.1% of all export-related value added. To compare the two types of exports, we analyzed the CO_2 emissions involved in 1,000 RMB of value added. When this value added is due to processing exports the emissions to value added ratio is smaller than in the case where the value added is due to non-processing exports. Depending on the assumptions we had to make for the emissions per unit of gross output in each of the three classes, the gap between the ratios was 34% or 13%.

Policy decisions still play an important role for industry performance in a "dual-track" economy like the Chinese (see Lau et al., 2000). In this respect, our results point to two types of policy recommendations. One is to stimulate the final demand for products from industries with the lowest ratio of CO_2 emissions to value added in Table 5.4. Examples would be the promotion of the exports by industries 1 (Agriculture), 20 (Instruments, meters, cultural and office machinery), and 8 (Wearing apparel, leather, furs, and related products).[26] The second type of policy would be to reduce the large emission to value added ratios. The best known example is industry 22 (Production and supply of electricity and heating power), which is a major polluter because its production still is largely coal-based. To a lesser extent, this holds for industries 13 (Nonmetal mineral products) and 14 (Metals smelting and pressing). Although an upgrading of the production techniques will require major investments,

[24] The focus in this study is on CO_2 emissions. We have found very similar results for SO_2 and NO_x emissions (which are given in Appendices 5.C and 5.D).

[25] This empirical finding is in line with the theoretical model developed by Silva and Zhu (2009). They show that free riding behavior may lead to double benefits for countries that are not exposed to an "ideal" global protocol (see also Copeland and Taylor, 2005 for theoretical aspects).

[26] It should be stressed that only CO_2 emissions are taken into account in this study. An in-depth policy advice would need to include also the evaluation of other (environmental and socio-economic) aspects. For example, taking China's water shortage into consideration, increasing the exports of agricultural products (in particular of very water-intensive products like rice and wheat) would be detrimental.

China's emissions will reduce drastically. It follows from Table 5.2 that the domestic final demands for these three products only accounts for 65% of all CO_2 emissions in China. If a 10% reduction in the emission intensities in these industries had been achieved in 2002, total CO_2 emissions in China would have reduced by 220 Mt (which, for example, equals one fourth of the emissions in Germany in 2002).

Appendix

5.A Industry classification

Number	Description
1	Agriculture
2	Coal mining, washing and processing
3	Crude petroleum and natural gas products
4	Metal ore mining
5	Non-ferrous mineral mining
6	Manufacture of food products and tobacco processing
7	Textile goods
8	Wearing apparel, leather, furs and related products
9	Sawmills and furniture
10	Paper and paper products, printing and reproduction
11	Petroleum processing, coking and nuclear fuel processing
12	Chemicals
13	Non-metal mineral products
14	Metals smelting and pressing
15	Metal products
16	Common and special equipment
17	Transport equipment
18	Electric equipment and machinery
19	Telecommunication equipment, computer and other electronic equipment
20	Instruments, meters, cultural and office machinery
21	Other manufacturing products
22	Production and supply of electricity and heating power
23	Gas production and supply
24	Water production and supply
25	Construction
26	Transport and warehousing
27	Wholesale and retail trade
28	Services

5.B Proof of equation (5-6)

From Figures 5.2 and 5.3, we have

$$\mathbf{Z} = \mathbf{Z}^{DD} + \mathbf{Z}^{ND} + \mathbf{Z}^{DP} + \mathbf{Z}^{NP} + \mathbf{Z}^{DN} + \mathbf{Z}^{NN}$$

and

$$\begin{aligned} <\mathbf{s}'\mathbf{Z}> &= <\mathbf{s}'(\mathbf{Z}^{DD} + \mathbf{Z}^{ND} + \mathbf{Z}^{DP} + \mathbf{Z}^{NP} + \mathbf{Z}^{DN} + \mathbf{Z}^{NN})> \\ &= <\mathbf{s}'(\mathbf{Z}^{DD} + \mathbf{Z}^{ND})> + <\mathbf{s}'(\mathbf{Z}^{DP} + \mathbf{Z}^{NP})> + <\mathbf{s}'(\mathbf{Z}^{DN} + \mathbf{Z}^{NN})> \end{aligned}$$

where $\mathbf{s}'$ is a summation vector with ones, $<\mathbf{y}>$ is used to indicate the diagonal matrix obtained from the vector $\mathbf{y}$ in case $\mathbf{y}$ is the product of a matrix and a vector. Because $\mathbf{Z} = \mathbf{A}\hat{\mathbf{x}}$ and $\mathbf{Z}^{RS} = \mathbf{A}^{RS}\hat{\mathbf{x}}^{S}$, we have

$$\begin{aligned} &<\mathbf{s}'\mathbf{A}>\hat{\mathbf{x}} = \\ &\quad <\mathbf{s}'(\mathbf{A}^{DD} + \mathbf{A}^{ND})>\hat{\mathbf{x}}^{D} + <\mathbf{s}'(\mathbf{A}^{DP} + \mathbf{A}^{NP})>\hat{\mathbf{x}}^{P} + <\mathbf{s}'(\mathbf{A}^{DN} + \mathbf{A}^{NN})>\hat{\mathbf{x}}^{N} \end{aligned} \qquad (5\text{-}5.\text{B})$$

According to equation (5-5), $\hat{\boldsymbol{\mu}} =<\mathbf{s}'\mathbf{A}><\mathbf{s}'(\mathbf{A}^{DR} + \mathbf{A}^{NR})>^{-1}\hat{\boldsymbol{\mu}}^{R}$, with $R = D, P, N$. Pre-multiplying both sides of (5-5.B) with $\hat{\boldsymbol{\mu}}<\mathbf{s}'\mathbf{A}>^{-1}$ and using $\hat{\boldsymbol{\mu}}<\mathbf{s}'\mathbf{A}>^{-1}$ $=\hat{\boldsymbol{\mu}}^{\mathbf{R}}<\mathbf{s}'(\mathbf{A}^{\mathbf{DR}} + \mathbf{A}^{\mathbf{NR}})>^{-1}$ gives

$$\hat{\boldsymbol{\mu}}\hat{\mathbf{x}} = \hat{\boldsymbol{\mu}}^{D}\hat{\mathbf{x}}^{D} + \hat{\boldsymbol{\mu}}^{P}\hat{\mathbf{x}}^{P} + \hat{\boldsymbol{\mu}}^{N}\hat{\mathbf{x}}^{N}$$

which completes the proof.

5.C SO_2 emissions (Kt) in each industry, per final demand category

	Domestic final demands		Exports		
	$\mathbf{f}^D$	$\mathbf{f}^N$	$\mathbf{e}^P$	$\mathbf{e}^N$	
Equation	(5-4a)	(5-4b)	(5-4c)	(5-4d)	
Industry					Total
1	278	15	4	28	325
2	228	42	8	47	325
3	77	8	1	10	95
4	35	1	0	1	37
5	49	1	1	4	55
6	251	46	6	30	334
7	105	5	13	84	207
8	6	0	1	3	11
9	26	4	2	6	39
10	147	14	17	25	203
11	138	5	3	11	157
12	1,120	67	55	153	1,394
13	1,408	124	29	157	1,718
14	6,184	413	77	592	7,266
15	49	2	2	9	62
16	110	16	2	9	138
17	70	8	2	7	87
18	21	0	1	3	26
19	10	0	1	1	11
20	2	0	2	1	5
21	33	2	2	6	42
22	8,342	3,010	219	1,361	12,932
23	19	3	1	5	28
24	2	1	0	0	4
25	99	0	0	1	101
26	263	16	17	61	357
27	100	7	13	25	145
28	117	6	2	10	135
Total (%)	19,289 (73.5)	3,819 (14.6)	481 (1.8)	2,650 (10.1)	26,239 (100.0)

5.D NO_x emissions (Kt) in each industry, per final demand category

	Domestic final demands		Exports		
	$\mathbf{f}^D$	$\mathbf{f}^N$	$\mathbf{e}^P$	$\mathbf{e}^N$	
Equation	(5-4a)	(5-4b)	(5-4c)	(5-4d)	
Industry					Total
1	165	9	2	17	193
2	115	21	4	24	164
3	78	8	1	10	97
4	22	0	0	1	23
5	28	0	1	2	31
6	133	25	3	16	176
7	56	3	7	45	110
8	4	0	1	2	7
9	14	2	1	3	20
10	76	7	9	13	104
11	110	4	2	9	125
12	373	22	18	51	464
13	618	55	13	69	754
14	423	28	5	40	497
15	31	2	1	6	40
16	66	10	2	6	83
17	40	5	1	4	50
18	15	0	1	2	18
19	12	0	1	1	13
20	1	0	2	1	4
21	20	1	1	4	26
22	4,747	1,713	124	774	7,360
23	4	1	0	1	5
24	1	1	0	0	2
25	88	0	0	1	90
26	1,509	91	96	352	2,048
27	61	4	8	15	89
28	204	11	4	17	236
Total (%)	9,013 (70.3)	2,024 (15.8)	308 (2.4)	1,484 (11.6)	12,830 (100.0)

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Introduction

The research in this thesis focused on the role of exports in the Chinese economy, taking into account that approximately half of China's exports are processing exports. The research thus contributes to the literature both methodologically and empirically. In particular, we provided a methodology for the treatment of processing trade and offered new insights into several empirical questions about the effects of China's exports. The new methodology was especially relevant for growth accounting issues, such as investigating the role of exports on import growth and income growth. The interregional input–output (IO) model was used to decompose the (dimensionless) normalized income multiplier in general and to examine how foreign exports in particular affect regional income. The linkage between foreign exports and the position of regions in production chains was investigated with net interregional income spillovers. Production fragmentation also affects the spatial distribution of production activities internationally and thus has implications for foreign trade and environmental issues. The linkage among processing trade, income generation, and greenhouse gas emissions is relevant for global climate change in an increasingly integrated world. Furthermore, we found that not taking processing trade into full account seriously biases the results. The findings are summarized in Section 6.2 and Section 6.3 gives some ideas for future research.

6.2 Summary of empirical results

Processing trade—mainly conducted by foreign-invested enterprises (FIEs)—has had a significant impact on the Chinese economy. Notably, FIEs use many imported intermediates in their production processes. Partly because of the growing importance of FIEs in the Chinese economy (particularly in Chinese exports), there is a debate regarding the sustainability of China's growth—that is, whether China is simply continuing along a path of labor-intensive industrialization in which productivity change is subservient to changes in the quantity of factor inputs. Specifically, it is widely believed that China's import growth is largely export driven.

Chapter 2 applied a structural decomposition analysis to Chinese IO tables to disentangle and quantify the sources of China's import growth and its growth in vertical specialization (i.e., China's incorporation into the global supply chain). To this end, we proposed a separate treatment of processing trade with customers' materials, which resulted in a new IO accounting scheme. We also incorporated the institutional characteristics of processing trade in an adapted definition of vertical specialization, the decomposition of which was further integrated into an import growth accounting framework.

Chapter 2 began from the observation that China's exports and the role of processing trade therein had increased substantially in the last decade. Yet it was found that aggregate exports and processing trade together accounted for only 38% of China's import growth from 1997 to 2005. Instead, the volume growth of China's domestic final demand was the most important determinant of China's import growth. Moreover, Chapter 2 shows that 35% of China's aggregate import growth could be attributed to changes in households' demand structure, technology, and import coefficients and the remainder to the volume growth of macro-economic demand. When compared with other countries, the structural change in IO coefficients and in the commodity composition of domestic final demand turned out to be surprisingly important. This indicates that tremendous structural changes occurred in the Chinese economy during this period.

At the same time, the contribution of aggregate export change to aggregate import growth was only 21%. Thus, the idea that Chinese import growth was mainly driven by its export growth found little empirical support. Rather, more important factors were structural change and the increase of China's domestic demand for imported products. Thus, the empirical results delivered evidence to the debate about whether China's growth is sustainable. We found that the sources of import growth in China largely came from structural changes that are sustainable.

It is also widely believed that exports, in particular of "high-tech" products, contribute greatly to China's income growth. In **Chapter 3**, the production for processing trade was separated from the production for ordinary trade.[1] Because processing trade has a rather different production structure (when compared with production for ordinary exports), it was necessary to explicitly distinguish between these two types of production by incorporating processing trade separately within the traditional Leontief model. An obvious reason for making this distinction was that around half of China's trade was processing trade. Two extended IO tables that distinguish production of processing exports and production of ordinary exports were employed to address this issue. The contribution of exports (including both their level and composition) to the value-added growth from 2002 to 2007 was found to be overestimated by 32% when standard IO tables were used rather than the extended IO tables.

Even more striking, the value-added growth that could be attributed to the exports of "high-tech" telecommunication products was overstated by no less than 63%. Our results indicated that "sophisticated exports," such as *telecommunications*, are less sophisticated than they appear at first sight, because they are based on significant foreign value added. The serious overestimation of the contribution to income growth of certain products (such as high-tech products) by traditional IO analysis sends misleading signals to policy makers. When measured correctly, the true contribution seemed substantially smaller than generally believed.

Methodologically, three refinements were made in applying a structural decomposition analysis (SDA). We explicitly took into account the substitution (i) between primary inputs and intermediate inputs, (ii) among intermediate inputs, and (iii) between the "home" origin and the "foreign" origin of intermediate inputs. It is worth noting that the extended SDA formula (which can easily be reduced to the standard form) can be adopted for other developing countries with considerable processing trade, such as Mexico, Indonesia, and Brazil. In addition to the conventional decomposition of sectoral value added growth, we introduced a way to

[1] This distinction is in line with heterogeneous firms' theory (Melitz, 2003). Specifically, two types of firms or production techniques coexist in a same industry. It is worth noting, however, that such superior treatment is not applied to Chapter 2 because the necessary data were not available for that study.

investigate the importance of product-specific causes (i.e., of domestic final demand growth by product and of foreign exports growth by product).

In **Chapter 4**, an interregional IO model was used to account for both intraregional indirect income effects and interregional income spillovers. By using China's modified 2002 and 2007 interregional IO tables, we investigated two distinct but inherently related empirical questions. First, we estimated interregional indirect income effects by means of the so-called normalized indirect income multiplier. Second, interregional income spillover effects due to foreign exports were studied as a specific application of interregional income multipliers. We found that coastal regions have relatively larger total national income effects—of, for example, an observed final demand change (such as exports) or a planned stimulus (e.g., investments)—than interior regions. Moreover, we found that *outgoing* interregional income spillovers account for one-quarter (for Northeast) to one-half (for Northern Municipalities) of total national indirect income multipliers in 2007, which is clearly not negligible when evaluating regional policy programs.

We also found that foreign exports from the East Coast and South Coast indirectly benefit three interior regions (Central Regions, Northwest, and Southwest) to a considerable extent. In percentages, for example, the interregional income spillovers to Central Regions from foreign exports in the East Coast represent 33.5% of the total value added generated in Central Regions by China's foreign exports. In other words, if foreign export growth in the East Coast would decrease (e.g., due to the financial crisis), the income growth in Central Regions would also contract.

In addition, a new measure (i.e., the net interregional income spillovers due to foreign exports) was developed to position China's individual regions (either upstream or downstream) in the global value chain. Three interior regions (Central Regions, Northwest, and Southwest) occupy the upstream positions, providing natural resources and raw materials, which are relatively far from final users. In contrast, the East Coast and South Coast are downstream regions with net interregional income spillovers to interior regions. Over time, these positions in the production chain became more pronounced.

Environmental problems were considered in **Chapter 5**. China's role in world trade has rapidly grown in recent years. For example, Chinese exports grew annually by almost 20% between 2001 and 2010 (compared with 9% for the world as a whole). In the policy debate, it has been expressed that China's emissions are increasingly caused by demand from foreign countries that import Chinese goods and services. At the same time, more than 55% of China's exports were related to international production fragmentation in 2002. In Chapter 5, we argue that producing these processing exports largely relies on imported intermediates and involves little domestic activity. Thus, these processing exports generate relatively little value added but also contribute relatively little to emission levels.

In an IO framework, the total amount of CO_2 emissions due to domestic final demand and foreign exports was calculated. Using an "ordinary" IO table, we found that 20.3% of the CO_2 emissions in 2002 were due to exports. However, using a special tripartite IO table that distinguishes processing exports from ordinary exports, we showed that only 12.6% of China's CO_2 emissions were due to exports.

Our observations show that production for processing exports is relatively clean. Specifically, the emissions to value added ratio was clearly smaller for processing exports than for non-processing exports. Depending on the assumptions for the emissions per unit of gross output in each of the three classes, the gap between the ratios was 13% or even 34%.

For policy decisions, our results led to two types of recommendations. The first is to stimulate the final demand (e.g., exports) for products with the lowest ratio of CO_2 emissions to value added. The second is to reduce the large emission to value-added ratios. The best-known example is the *production and supply of electricity and heating power industry*, which is a major polluter because its production still is largely coal based.

6.3 Directions for future research

The production for processing exports should be clearly distinguished from other production. From the viewpoint of methodology, a novel treatment of processing trade has been developed (in Chapters 2 and 4). In addition, we propose a new method to incorporate distinct features of processing exports and ordinary exports in one consistent framework (in Chapters 3 and 5). In this way, we were able to clarify certain debates and questions. For example, is China's growth sustainable? Do exports of "*high-tech*" products contribute much to China's income growth? Should China be held accountable for all its emissions given the large number of exports that are consumed overseas? Finally, the link between interregional trade and foreign exports and the position of China's regions in the production chain has been explicitly dealt with empirically (in Chapter 4).

Some interesting topics remain untouched due to time limits. For example, we also may take the global value chain (GVC) perspective. Today, international fragmentation increasingly has become the norm rather than the exception. Because inputs cross borders several times, traditional statistics on trade (i.e., imports and exports in gross terms) do not fully reflect the position of a particular country and the role it plays in a global context. New measures of trade are called for to meet the increasing demand from policy makers and the public for a better understanding of the nature of cross-border trade in today's increasingly integrated world.

For example, WTO directory-general Pascal Lamy, jointly with the OECD, launched the "made in the world" initiative and proposes "trade in value added" as a better measurement for international trade.[2] In this regard, the WIOD project (World Input-Output Database, www.wiod.org) is timely[3] because a global inter-country IO model is needed to account for trade in value added. One possible direction is to couple (i) the tripartite IO table for China into for example WIOD and (ii) the Chinese interregional IO table into WIOD.

Another important issue is the income disparity or inequality issue confronting China's policy makers. The "*Twelfth Five-Year Plan*" describes visions of prosperity

[2] More information can be found in the document "Measuring Trade in Value-Added: An OECD-WTO joint initiative," available at: http://www.oecd.org/sti/industryandglobalisation/measuringtradeinvalue-addedanoecd-wtojointinitiative.htm. See also the WIOD website with papers on GVC and the speeches by EC commissioner Karel De Gucht and WTO deputy director Alejandro Jara (available at: www.wiod.org).

[3] Alternatively, one may wish to use other databases such as GTAP (Global Trade Analysis Project). The main difference between these two databases lies in their different treatment of benchmarks. WIOD gives more weight to the so-called supply and use tables while GTAP relies more on trade data in connection with IO tables. (Note: GTAP has many national tables but does not have intercountry tables.) It is worth noting that an important advantage of WIOD over other multi-regional IO databases is that it provides time series IO tables (both in current and previous year's prices) and provides detailed satellite accounts with socio-economic data (such as labor by skill types and corresponding wages) and environmental data (such as natural resources by type and emissions by type).

and more equity in China at great length. Several regional development programs have been launched in the last decade, aiming at narrowing per capita income gaps among regions. To evaluate their effects, China's interregional IO model must be extended. Relevant extensions would include three issues. First, more years. Second, the incorporation of China's trade statistics that distinguish processing trade and ordinary trade by commodity per province. Third, the augmentation of the tables with labor by skill type, or natural resource by type. For example, linking skill types to average wages would provide important information on disparity. Also, additional data on resources could provide information on the comparative advantage of regions when demand increases. In this way, it's possible to provide explanations for the income disparity and draw insightful policy suggestions.

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SAMENVATTING

Dit proefschrift richt zich op de rol van export voor de Chinese economie. De Chinese export bestaat voor ongeveer de helft uit verwerkingsexport (*processing exports*). Dit typische kenmerk van de Chinese handel moet op de juiste manier worden benaderd. Het onderzoek levert een bijdrage op zowel methodologisch als empirisch vlak. We ontwikkelen een methodologie om de verwerkingshandel te benaderen en verkrijgen daarmee nieuwe inzichten in een aantal empirische vragen over het effect van de Chinese export.

De nieuwe methodologie is met name relevant gebleken voor de *growth accounting*, bijvoorbeeld waar de rol van export voor importgroei en inkomensgroei wordt onderzocht. Het interregionale input-output model wordt gebruikt om de genormaliseerde inkomensmultiplier te ontleden en om te onderzoeken hoe het regionale inkomen door de export wordt beïnvloed. Het verband tussen de export en de positie van regio's in mondiale productieketens is onderzocht aan de hand van netto interregionale inkomens spillovers. Internationale productiefragmentatie heeft niet alleen impact op de ruimtelijke distributie van productieactiviteiten, maar ook op milieukwesties. Het verband tussen verwerkingshandel en de uitstoot van broeikas gassen is van belang voor mondiale klimaatverandering in een steeds meer geïntegreerde wereld. Eerder is gebleken dat de resultaten ernstig worden vertekend als er geen rekening wordt gehouden met de verwerkingshandel.

Verwerkingshandel, die met name wordt bedreven door met buitenlands kapitaal gefinancierde ondernemingen (FIE's), heeft een aanzienlijke impact op de Chinese economie. FIE's gebruiken veel geïmporteerde halffabricaten in hun productieprocessen. Daar het belang van FIE's voor de Chinese economie toeneemt (met name voor de Chinese export), is er een debat ontstaan over de vraag of de Chinese groei wel of niet duurzaam is. Met andere woorden, blijft China wel of niet het pad van arbeidsintensieve industrialisatie bewandelen, waarin productieverandering ondergeschikt is aan veranderingen in de kwantiteit van de productiefactoren?

De mening dat de Chinese importgroei grotendeels wordt gedreven door export lijkt door velen te worden gedeeld. In **hoofdstuk 2** wordt een structurele decompositie analyse op Chinese input-output (IO) tabellen toegepast teneinde de bronnen van de

Chinese importgroei te ontleden en te kwantificeren. Datzelfde wordt gedaan voor de groei in verticale specialisatie, die aangeeft in welke mate China in mondiale toeleveringsketens is opgenomen. In de analyse stellen wij een afzonderlijke benadering van de verwerkingshandel met klantmaterialen voor, wat in een nieuw IO-rekeningenstelsel heeft geresulteerd. Daarnaast zijn de institutionele kenmerken van verwerkingshandel opgenomen in een aangepaste definitie van verticale specialisatie, waarvan de ontleding verder is geïntegreerd in een decompositie analyse van de importgroei.

Hoofdstuk 2 begint met de constatering dat de Chinese export en de rol van verwerkingshandel hierin de laatste tien jaar aanzienlijk zijn toegenomen. Toch is gebleken dat de totale export en de verwerkingshandel in de periode 1997-2005 samen voor slechts 38% van de Chinese importgroei verantwoordelijk zijn; de volumegroei van de Chinese binnenlandse finale vraag bleek de belangrijkste determinant. Ook wordt in hoofdstuk 2 aangetoond dat 35% van de totale Chinese import groei kan worden toegeschreven aan veranderingen in de vraagstructuur van huishoudens en in technologie- en importcoëfficiënten, en het overige deel aan de volumegroei van de macro-economische vraag. De structurele verandering in IO coëfficiënten en in de goederensamenstelling van de binnenlandse finale vraag bleek in vergelijking met andere landen verrassend belangrijk. Dit geeft aan dat er tijdens deze periode enorme structurele veranderingen in de Chinese economie hebben plaatsgevonden.

Tegelijkertijd bedroeg de bijdrage van de totale exportverandering aan de totale importgroei slechts 21%. Daarom vond de veronderstelling dat de Chinese importgroei voornamelijk werd aangedreven door de exportgroei maar weinig empirische steun. De empirische resultaten leverden bewijs voor het debat of de Chinese groei duurzaam is. Er werd aangetoond dat de Chinese importgroei met name werd veroorzaakt door structurele veranderingen die als duurzaam kunnen worden beschouwd.

Een andere wijdverbreide overtuiging is dat de export van met name hightech producten een grote bijdrage levert aan de Chinese inkomensgroei. In **hoofdstuk 3** wordt de productie voor de verwerkingshandel gescheiden van de productie voor de gewone handel. [1] Gezien de grote verschillen in productiestructuur (tussen verwerkingshandel en gewone handel) was het noodzakelijk om een expliciet onderscheid te maken tussen deze twee productietypes; de verwerkingshandel is dan ook afzonderlijk opgenomen in het traditionele Leontief model. Gegeven het feit dat ongeveer de helft van de Chinese handel uit verwerkingshandel bestaat verwachtten wij dat de resultaten door het maken van dit onderscheid aanzienlijk veranderen. Om de bijdrage aan de inkomensgroei nader te onderzoeken zijn er twee uitgebreide IO-tabellen gebruikt waarin onderscheid wordt gemaakt tussen de productie van de verwerkingsexport en de productie van de gewone export. Bij het gebruik van de standaard - in plaats van de uitgebreide IO tabellen bleek dat voor de periode 2002-2007 de bijdrage van de export (zowel het niveau als de samenstelling ervan) aan de groei van de toegevoegde waarde met 32% werd overschat.

Nog opvallender is dat de groei van de toegevoegde waarde die kon worden toegeschreven aan de export van hightech telecommunicatieproducten werd overschat met maar liefst 63%. Uit onze resultaten is gebleken dat 'hightech export', zoals telecommunicatie, minder hightech is dan deze op het eerste gezicht lijkt, omdat deze export op veel buitenlandse toegevoegde waarde is gebaseerd. De grote overschatting van de bijdrage van bepaalde producten (zoals hightech producten) aan de inkomensgroei in een traditionele IO analyse geeft misleidende signalen in de richting van beleidsmakers. Toen deze correct werd gemeten, bleek de daadwerkelijke bijdrage aanzienlijk kleiner te zijn dan over het algemeen werd gedacht.

In de toepassing van de structurele decompositie analyse (SDA) zijn drie methodologische verfijningen aangebracht. Wij hebben expliciet rekening gehouden met de substitutie tussen (i) primaire en intermediaire inputs, (ii) intermediaire inputs onderling, en (iii) de binnenlandse en buitenlandse oorsprong van intermediaire inputs. Ook moet worden opgemerkt dat de uitgebreide SDA-formule kan worden toegepast op andere ontwikkelingslanden met een aanzienlijke verwerkingshandel, zoals Mexico, Indonesië en Brazilië. Naast de conventionele decompositie van de sectorale groei van de toegevoegde waarde hebben we een manier geïntroduceerd om het

[1] Dit onderscheid is conform de theorie betreffende heterogene bedrijven (Melitz, 2003), waarin twee verschillende types bedrijven of productietechnieken naast elkaar bestaan in dezelfde industrie. Er moet worden opgemerkt dat deze benadering niet is toegepast in hoofdstuk 2 omdat de daarvoor noodzakelijke gegevens niet beschikbaar waren voor deze studie.

belang van product-specifieke oorzaken te onderzoeken, m.a.w. van de verandering in de binnenlandse finale vraag per product of buitenlandse export per product.

In **hoofdstuk 4** is een interregionaal input-output model gebruikt om in de indirecte sfeer de intraregionale indirecte inkomenseffecten van de interregionale inkomens spillovers te onderscheiden. Aan de hand van de (voor verwerkingsexporten) aangepaste Chinese interregionale IO tabellen van 2002 en 2007 werden er twee verschillende maar inherent verbonden empirische vragen onderzocht. Ten eerste werden interregionale indirecte inkomenseffecten geschat aan de hand van de zogenoemde genormaliseerde indirecte inkomensmultiplier. Ten tweede werden de door de export veroorzaakte interregionale inkomens spillover effecten onderzocht als een specifieke toepassing van interregionale inkomensmultipliers. Vergeleken met regio's in het binnenland vertoonden de kustregio's een relatief groter totaal nationaal inkomenseffect van bijvoorbeeld een verandering in de finale vraag (zoals export) of een geplande stimulans (zoals investeringen). Ook bleek dat in 2007 de *uitgaande* interregionale inkomens spillovers een kwart (in het Noordoosten) tot de helft (in de Beijing-Tianjin regio) uitmaakten van de totale nationale indirecte inkomensmultiplier; cijfers die duidelijk niet kunnen worden genegeerd bij het evalueren van regionale beleidsprogramma's.

Daarnaast bleek dat de export vanuit de Oostkust en Zuidkust een drietal binnenlandse regio's (de Centrale regio's, het Noordwesten en het Zuidwesten) in aanzienlijke mate ten goede komt. De interregionale inkomens spillovers naar de Centrale regio's van de export vanuit de Oostkust bedragen bijvoorbeeld 33,5% van de totale toegevoegde waarde die door de Chinese export in de Centrale regio's wordt gegenereerd. Met andere woorden, als de exportgroei aan de Oostkust zou afnemen (bijv. door de financiële crisis), dan zal de inkomensgroei in de centrale regio's ook verminderen.

Voorts is er een nieuwe maatstaf ontwikkeld (namelijk de door de export veroorzaakte netto interregionale inkomens spillovers) om de afzonderlijke Chinese regio's (zowel stroomopwaarts als stroomafwaarts) in de mondiale waardeketen te positioneren. De drie binnenlandse regio's (de Centrale regio's, het Noordwesten en het Zuidwesten) bezetten stroomopwaartse posities en leveren natuurlijke hulpbronnen en grondstoffen, die zich op relatief grote afstand van de eindgebruikers bevinden. De Oostkust en de Zuidkust zijn daarentegen stroomafwaartse regio's met netto interregionale inkomens spillovers naar de binnenlandse regio's. Deze posities in de productieketen zijn van 2002 op 2007 meer uitgesproken geworden.

In **hoofdstuk 5** wordt gekeken naar milieuproblemen. De rol van China in de wereldhandel is de laatste jaren snel gegroeid. Tussen 2001 en 2010 is de export jaarlijks met bijna 20% gestegen (vergeleken met 9% wereldwijd). In het beleidsdebat wordt beweerd dat de Chinese uitstoot vooral wordt veroorzaakt door de vraag uit het buitenland. In 2002 was echter meer dan 55% van de Chinese export gerelateerd aan de internationale productiefragmentatie. In hoofdstuk 5 wordt beargumenteerd dat de productie van deze verwerkingsexport grotendeels afhankelijk is van geïmporteerde halffabricaten en dat hier zeer weinig binnenlandse activiteiten bij betrokken zijn. Deze verwerkingsexport genereert daarom relatief weinig toegevoegde waarde, maar ook relatief weinig uitstoot.

Het totaal aan CO_2-uitstoot dat wordt veroorzaakt door de binnenlandse finale vraag en door de export is berekend met een IO model. Gebruikmakend van een 'gewone' IO-tabel bleek dat in 2002 ruim 20% van de CO_2-uitstoot werd veroorzaakt door de export. Gebruikmakend van een speciale driedelige IO tabel, waarin onder andere onderscheid wordt gemaakt tussen de verwerkingsexport en de gewone export, bleek echter dat slechts een kleine 13% van de Chinese CO_2-uitstoot werd veroorzaakt door de export.

Ook werd duidelijk dat de productie voor de verwerkingsexport relatief schoon is. De uitstoot/toegevoegde waarde ratio was beduidend kleiner voor de verwerkingsexport dan voor de gewone export. Afhankelijk van de aannames voor de uitstoot per eenheid omzet in elk van de drie klassen bedroeg het gat tussen de ratio's 13% of zelfs 34%.

Onze resultaten wijzen op twee soorten aanbevelingen voor beleidsbeslissingen. Ten eerste moet de finale vraag (bijv. export) naar producten met de laagste ratio CO_2-uitstoot/toegevoegde waarde worden gestimuleerd. Ten tweede moeten de hoge uitstoot/toegevoegde waarde ratio's worden gereduceerd. Het bekendste voorbeeld is de productie en het aanbod van de elektriciteits- en verwarmingsindustrie, een grote vervuiler omdat de productie nog steeds grotendeels op kolen is gebaseerd.

Uit dit proefschrift is duidelijk geworden dat de productie voor verwerkingsexport onderscheiden moet worden van andersoortige productie. Vanuit het oogpunt van methodologie is een nieuwe benadering van de verwerkingshandel ontwikkeld (in hoofdstukken 2 en 4). Ook is er een nieuwe methode voorgesteld om de specifieke kenmerken van verwerkingsexport en gewone export in één consistent kader op te nemen (in hoofdstukken 3 en 5). Op deze manier kunnen we bepaalde debatten en vragen verduidelijken: is de Chinese groei duurzaam? Hoe groot is de bijdrage van hightech producten aan de Chinese inkomensgroei? Moet China verantwoordelijk worden gehouden voor al haar uitstoot terwijl veel export overzee wordt geconsumeerd? Daarnaast is het verband tussen de interregionale handel, de export en de positie van de Chinese regio's in de mondiale productieketen op expliciete wijze empirisch behandeld (in hoofdstuk 4).